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PHOSPHORUS ADSORPTION BY FIVE ALABAMA SOILS AS INFLUENCED BY REACTION, BASE SATURATION, AND FREE SESQUIOXIDES[1]

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SOIL scientists agree that when soluble phosphatic fertilizers are applied to the soil a portion of the phosphate ions is rendered insoluble by components of the colloidal fraction of the soil. Much work has been done to clarify the behavior of phosphates in the soil, but there is still a lack of agreement in the interpretation of the results obtained. This lack of agreement arises in part from the controversial ideas as to the components active in the fixation process.

Many investigators (2, 4, 5, 7, 9, 10, 11, 12, 13, 14)[3] have found that iron gels or iron compounds in the soil are very active in phosphate fixation. Beater (1) has pointed out that within the pH range of most acid soils the phosphorus is fixed largely as iron and aluminum phosphates or the more insoluble basic phosphates of these cations.

Gaarder (5) has clearly set forth the behavior of the phosphate ion in the presence of free ions of iron, aluminum, calcium, magnesium, and sodium. He believed that within the pH range of normal soils iron and aluminum were of prime importance in controlling phosphate solubility, even though he worked with chemically pure materials in the absence of soil. He also found that sodium silicate was effective in increasing phosphate solubility, presumably by the precipitation or "de-activation" of the sesquioxides, while Scarseth (10) on verifying this work believed that the phosphate ion replaced the silicate ion in the complex colloidal silicates.

Gilligan (6) showed that as the degree of calcium saturation of the base exchange complex was increased, the amount of PO_4 adsorbed was increased in most cases. The lowest phosphate adsorption neither took place at any definitely restricted range of pH, nor was there a well-defined relationship between ex-

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[3]Reference by numbers in parenthesis is to "Literature Cited", p. 12.

changeable calcium and phosphate fixation. Cook (3) showed that the addition of lime to soils caused significant increases in the amounts of readily available soil phosphates. The soils used by these investigators were not treated to remove the free iron and aluminum oxides.

For a detailed review of the literature pertaining to the subject of this paper the reader is referred to Murphy (8) or Beater (1).

The purpose of the present investigation was to obtain additional information on the effect of the kinds of cations contained in the base exchange complex and the presence and absence of free iron and aluminum oxides upon the adsorption of phosphorus by five Alabama soils. The cations employed were hydrogen, calcium, sodium, and magnesium. The term "adsorption" as used herein has reference to the removal of phosphorus from solution by the clays regardless of the manner or agency.

EXPERIMENTAL

COLLECTION AND PREPARATION OF SAMPLES

Samples of Decatur, Hartsells, Houston, Norfolk, and Cecil soils were taken to a depth of 6 inches from areas that had not been fertilized for at least 8 years. The clay fraction of each soil (particles $< 5\ \mu$ diam.) was obtained from soil-water suspensions on the basis of Stoke's law. These clay suspensions were then concentrated to approximately 10% clay and divided into two portions. One portion was electrodialyzed using a potential of 120 volts until free of mobile ions. After electrodialysis, these suspensions were made up to contain 5% clay. The other portion of each clay was treated to remove its free Fe_2O_3, Al_2O_3, and amorphous SiO_2, employing the method proposed by Truog and his co-workers (16). After the free oxides were removed the suspensions were electrodialyzed and made up to contain 5% clay, with the exception of the Houston, which was made up to a 2.5% suspension. The Houston clay formed a voluminous mass having about three times the original volume. This necessitated a suspension of only 2.5%.

The base exchange capacity of each clay was determined by leaching 5 grams of clay with 2 liters of normal $CaCl_2$ solution. After the excess calcium chloride was removed, the exchangeable calcium was replaced by leaching the samples with 2 liters of neutral normal ammonium acetate solution, and the calcium was determined by the regular volumetric procedure. After the excess ammonia was washed out of the sample, the ammonia in the base exchange complex was then determined, giving a second measure of the exchange capacity. In this way the exchange capacity of each soil was checked.

The degree of cation saturation with hydrogen, calcium, sodium, and magnesium was varied in the adsorption studies. The method of saturating the exchange complex to various degrees was as follows: Suspensions of the hydrogen-saturated clays were placed in flasks and the desired cation was added as the hydroxide, except magnesium which was added as $MgCO_3.3H_2O$, in amounts equal to the exchange capacity of each individual clay. The flasks were shaken frequently and allowed to stand for at least one month before the clays were used

in the adsorption studies. On determining the degree of cation saturation after this treatment, it was found that the base exchange complex was not saturated (Table 1). The term "partially saturated" will be used hereafter in this report for samples treated in this manner.

Since complete cation saturation was not obtained by treating the clays in this manner, another set of clay samples was leached with a large excess of the various cations to obtain complete saturation. On determining the degree of cation saturation, it was found that the base exchange complex was completely saturated.

In the remainder of this report, the samples which were treated to remove their free Fe_2O_3, Al_2O_3, and amorphous SiO_2 will be referred to as "treated" clays and those not having been treated as "untreated" clays.

PRELIMINARY TESTS OF BASE SATURATION

Preliminary tests were conducted using hydrogen clay in order to determine the most desirable methods of saturating the clays with phosphate. A series of 0.2-, 0.5-, 1.0-, and 1.5-gram samples of clay was suspended in 100 cc of water containing 10, 40, and 100 p.p.m. of P as H_3PO_4. The suspensions were shaken frequently and aliquots for P_2O_5 determinations were taken at the end of 1, 2, 5, and 10 days. The data obtained showed that the 1.0-gram sample was the most desirable size to use and that the 2-day interval was satisfactory since the adsorption of phosphates by the clays was practically complete by the end of 2 days as pointed out by Scarseth and Tidmore (11, 12). The data showed that a maximum adsorption of phosphate by the 1.0-gram samples occurred when the solution contained 100 p.p.m. P.

The data obtained in preliminary studies and presented in Table 1 give the base exchange capacities of the clays and the degree of calcium saturation produced by the method which was presumed to give complete saturation. The data show that the exchange capacity varied from 24.20 to 77.20 M.E. in the clays studied. The exchange capacity of the Decatur and Houston clays was lowered by the treatment used to extract the free oxides; whereas, in the Hartsells, Norfolk, and Cecil clays it was not altered appreciably. This may be due to the destruction of organic matter in the Decatur and Houston clays which were the only two soils that contained an appreciable amount of organic matter.

The data in Table I show clearly that the method employed to prepare clay samples of the desired degree of base saturation was not entirely satisfactory. The degree of saturation obtained varied with each soil and with its previous treatment. In the Decatur, Norfolk, and Houston clays the method gave fair results except for the treated Norfolk which was only 55% as saturated as the untreated sample. There was no correlation between the degree of saturation and SiO_2/R_2O_3 ratio of the clay fractions.

PROCEDURE IN ADSORPTION STUDIES

One-gram samples of clay that had been saturated 100% with H; or 66.7% H and 33.3% Ca, Na, or Mg; or 33.3% H and 66.7% Ca, Na, or Mg; or similar combinations using the various cations, were placed in 100-cc portions of water solution containing 100 p.p.m. of phosphorus. The source of phosphorus for the solutions was either H_3PO_4, $CaH_4(PO_4)_2$, $MgH_4(PO_4)_2$, NaH_2PO_4, Na_2HPO_4, or Na_3PO_4. When the clay samples contained two or more cations in a definite ratio, the sources of phosphorus were used in such combinations as not to alter appreciably the ratio of exchangeable cations of the clays.

Clear aliquots for P_2O_5 determination were easily obtained, except when sodium was used, by pipetting the clear solution above the flocculated clays. Aliquots of the sodium-treated samples were placed in centrifuge tubes and centrifuged at approximately 2,500 r.p.m. for 20 minutes to throw out most of the colloids. All solutions were then analyzed for P_2O_5 by the Deneges colorimetric method as modified by Truog (15).

Immediately following the removal of aliquots for P_2O_5 determination, the samples were thoroughly agitated and the pH of the suspensions were determined with a glass electrode.

TABLE 1.—*The base exchange capacity and the degree of calcium saturation produced when amounts of $Ca(OH)_2$ were added to produce 100% theoretical calcium-saturated clays.*

Colloid <5 μ from	Base exchange capacity M.E. per 100 grams		Degree of calcium saturation, %	
	Untreated	Treated	Untreated	Treated
Cecil soil.........	24.20	25.20	58.1	62.0
Hartsells soil......	27.04	27.20	54.3	46.0
Decatur soil......	32.85	27.36	91.3	80.0
Norfolk soil.......	36.40	37.20	94.4	52.1
Houston soil......	77.20	66.26	92.3	95.7

RESULTS AND DISCUSSION

INFLUENCE OF VARIOUS EXCHANGEABLE CATIONS ON PHOSPHORUS ADSORPTION

It is obvious that the nature of the various cations in the base exchange complex of a soil will influence the adsorptive reactions within that system. The data in Table 2 show the influence exerted upon the adsorptive power of the various treated and untreated clays when they were completely saturated and when theoretically saturated with various cations. With the exception of the treated Hartsells, either the hydrogen- or calcium-saturated clays adsorbed the greatest amount of phosphorus. In no instance did the sodium clays adsorb a significant amount of phosphorus from solution. The magnitude of adsorption by the untreated clays varied from lowest to highest in the order of sodium, magnesium, calcium, and hydrogen, respectively. The pH values varied in the reverse order. In all cases the completely saturated clays adsorbed more phosphorus than did the corresponding theoretically saturated samples with the exception of the sodium-saturated clays which adsorbed very little or no phosphorus. The untreated samples adsorbed a greater amount of phosphorus than did the corresponding treated sample.

The data (Table 2) show that different forms of adsorption occurred in the hydrogen clay samples. The pH values of the untreated samples were sufficiently high to permit precipitation of iron and aluminum phosphates but not sufficiently high for much anion adsorption to occur since Scarseth (10) and others believe that anion adsorption occurs most readily between pH 5.0 to 6.0. In the corresponding treated samples, the pH was too low for much anion adsorp-

tion to occur; however, some phosphate adsorption did occur and may be attributed to the formation of iron phosphate since the treatment to remove sesquioxides may have left a small amount of them in the clay. On this basis, the adsorption by the hydrogen clays probably was caused almost entirely by the formation of insoluble iron and aluminum phosphates. The Houston and Cecil clays were the only two treated clays that adsorbed a significant amount of phosphorus.

When the clays were saturated with calcium, the adsorptive capacity of the treated clays and two of the untreated clays was increased. The pH values were sufficiently high to permit the precipitation of $Ca_3(PO_4)_2$ in all cases except for the treated clays partially saturated. This probably accounts for the increased adsorption by the treated clays. Since the phosphorus was added to the samples after the calcium had been applied and the pH values raised, some of the iron and aluminum may have been "de-activated" and, therefore, did not enter into the adsorption reactions. The clays completely saturated with calcium adsorbed more phosphorus than did the clays partially saturated with calcium as would be expected, since more calcium was present and the pH values were higher.

No appreciable adsorption occurred in any of the treated or untreated sodium clays. Since sodium hydroxide is an excellent solvent for iron and aluminum phosphates and small amounts of it probably were formed by hydrolysis, iron and aluminum phosphates probably could not be formed.

The magnesium-saturated clays adsorbed a significant amount of phosphorus but not as much as did the hydrogen or calcium clays. The pH values were within the range where anion adsorption might occur and for some iron, aluminum, and magnesium precipitation; however, the iron or aluminum phosphates would be almost completely hydrolyzed and the magnesium phosphates would be slightly soluble at that pH value. Apparently the difference in adsorption between the treated and untreated samples was due to iron and aluminum precipitation in the latter.

INFLUENCE OF NATURE OF BASE SATURATION

The data presented in Figs. 1 and 2 show the influence of the degree of hydrogen saturation on phosphorus adsorption when used in combination with either calcium, sodium, or magnesium on untreated and treated clays.

The addition of calcium, sodium, or magnesium to the untreated hydrogen clays reduced the adsorptive power of the clays in all cases except the Decatur and Hartsells clays where the addition of calcium slightly increased their adsorptive power. It can be seen from the graphs that sodium had the greatest depressing effect upon the amount of phosphorus adsorption, magnesium an intermediate effect, and calcium the least influence. This was true in the treated as well as the untreated clays, although the trend in the hydrogen-calcium series of the treated clays was not in the exact order as the others nor as pronounced.

TABLE 2.—*Influence of different cations upon phosphorus adsorption by various clays.*

Degree of base saturation, %				Phosphorus adsorption (p.p.m.) and pH values			
				Untreated		Treated	
H	Ca	Na	Mg	P	pH	P	pH
				Decatur			
100	—	—	—	48.7	3.26	8.7	2.55
—	100	—	—	42.5	6.95	28.7	6.78
—	100*	—	—	32.5	5.96	12.0	3.46
—	—	100	—	0	10.41	−0.1	10.55
—	—	100*	—	0	9.96	−0.3	10.65
—	—	—	100	27.6	7.62	8.5	7.60
—	—	—	100*	16.0	7.02	0	6.32
				Hartsells			
100	—	—	—	48.1	3.13	2.2	2.35
—	100	—	—	36.9	6.58	10.0	6.45
—	100*	—	—	31.0	5.90	9.5	3.31
—	—	100	—	2.5	10.24	1.8	10.55
—	—	100*	—	0.2	10.57	−0.7	10.66
—	—	—	100	38.8	7.32	12.2	7.75
—	—	—	100*	20.0	6.79	2.5	6.41
				Houston			
100	—	—	—	28.4	3.30	17.5	2.45
—	100	—	—	54.1	6.55	47.9	5.50
—	100*	—	—	35.0	6.01	9.0	3.85
—	—	100	—	−0.9	10.63	0.1	9.72
—	—	100*	—	−0.7	11.15	0	10.13
—	—	—	100	30.3	7.71	19.4	7.30
—	—	—	100*	17.5	7.41	10.0	6.41
				Norfolk			
100	—	—	—	33.7	3.00	5.6	2.35
—	100	—	—	29.2	6.63	12.9	6.55
—	100*	—	—	22.0	5.84	5.0	3.66
—	—	100	—	0.2	9.62	0	9.70
—	—	100*	—	−0.2	10.48	−0.9	10.77
—	—	—	100	20.3	7.55	9.4	7.35
—	—	—	100*	9.0	6.80	0	6.58
				Cecil			
100	—	—	—	61.2	3.13	30.0	2.74
—	100	—	—	70.1	6.65	63.8	5.95
—	100*	—	—	30.0	5.90	20.0	3.28
—	—	100	—	2.2	10.65	1.0	10.24
—	—	100*	—	−1.1	10.96	−0.9	10.55
—	—	—	100	40.8	7.40	27.2	6.72
—	—	—	100*	19.0	6.83	10.5	5.65

*Theoretical per cent saturation.

Figs. 3 and 4 show the influence of the nature of saturation of the exchange complex upon phosphorus adsorption when any two of the three cations, calcium, sodium, and magnesium, were added

to the untreated and treated clay. It is apparent that the addition of either sodium or magnesium to calcium clays and sodium to

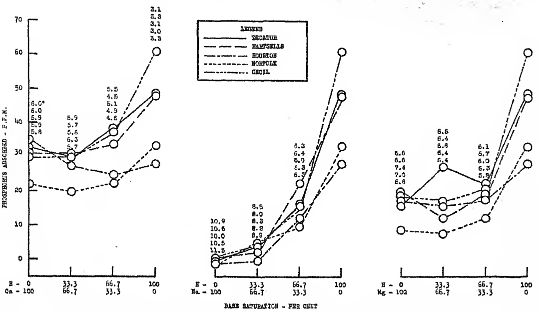

FIG. 1.—Influence of degree of hydrogen saturation of the exchange complex upon phosphorus adsorption by the untreated clays.

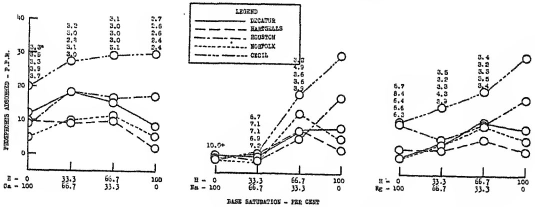

FIG. 2.—Influence of degree of hydrogen saturation of the exchange complex upon phosphorus adsorption by the treated clays.

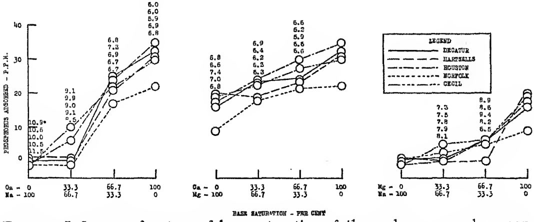

FIG. 3.—Influence of nature of base saturation of the exchange complex upon the adsorption of phosphorus by the untreated clays.

magnesium clays had a decidedly depressive effect on the adsorption of phosphorus by the clays; however, the depressive effect was less evident for the calcium-magnesium series of the treated clays. Again it was seen that sodium had the greatest depressive effect of any cation and, also, that its influence was more pronounced when used in combination with magnesium than when used with any other cation.

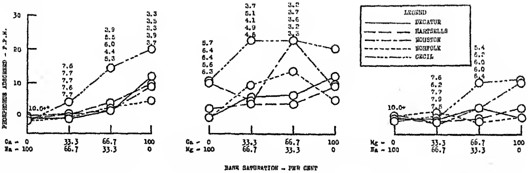

FIG. 4.—Influence of nature of base saturation of the exchange complex upon the adsorption of phosphorus by the treated clays.

Figs. 5 and 6 show the amount of phosphorus absorbed by the untreated and treated clays when saturated with three cations in equal amounts. In the untreated clays (Fig. 5) it is apparent that the clays adsorbed a significant amount of phosphorus when saturated with any combination except hydrogen, sodium, and magnesium. The calcium, sodium, and magnesium series tended to adsorb the greatest amount of phosphorus; the hydrogen, calcium, and magnesium second; the hydrogen, calcium, and sodium third; and the hydrogen, sodium, and magnesium least. The amount of adsorption was small in all the treated clays except for Cecil and its trend was in the same order as the untreated clays.

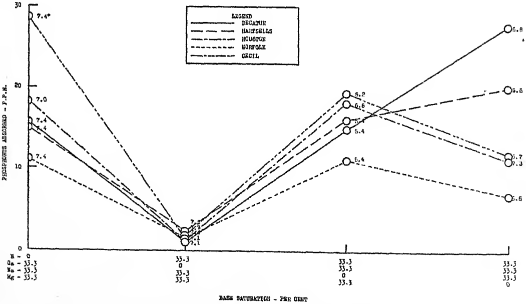

FIG. 5.—Influence of base saturation with three cations in equal quantities upon phosphorus adsorption by the untreated clays.

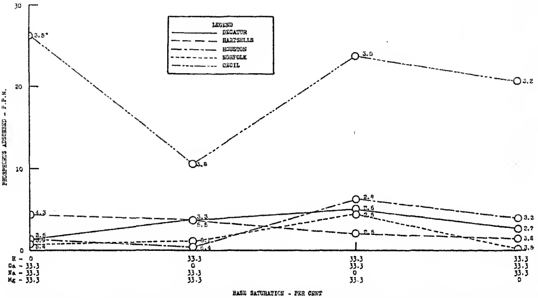

FIG. 6.—Influence of base saturation with three cations in equal quantities upon phosphorus adsorption by the treated clays.

A study of the pH data along with the curves presented in Fig. 1 reveals a plausible explanation for the general trends established. The hydrogen-saturated clays usually adsorbed a greater amount of phosphorus than any of the other clays. This was probably due to the reaction between iron or aluminum oxides and phosphate to form insoluble compounds and possibly to some anion adsorption. On the other hand, where the free iron and aluminum oxides had been extracted, there was less adsorption of phosphorus except in the Cecil and Houston clays (Fig. 2). As increments of calcium were added to the untreated clays the pH values were raised and there was less iron and aluminum brought in solution to precipitate insoluble phosphates. When the calcium saturation was increased to 100%, the curves began to rise again because the pH values were raised to the point that $Ca_3(PO_4)_2$ would begin to precipitate.

The addition of increments of sodium to the hydrogen clays caused a tremendous decrease in the phosphorus adsorption in the untreated clays (Fig. 1) and a similar but smaller decrease in the treated clays (Fig. 2). This fact was readily appreciated when a study of the pH values was made which showed that they were too high for much anion adsorption to occur and were high enough to cause considerable hydrolysis of iron and aluminum phosphates. The depressive effect of the sodium was not as great in the treated clays since there was less adsorption by the hydrogen clay and there was little, if any, iron or aluminum phosphates present to be hydrolyzed.

The depressive effect of the magnesium upon the adsorption of phosphates by hydrogen clays was very pronounced but not as great as that of sodium and greater than that of calcium. Again, the addition of the basic cation decreased the acidity and caused less iron and aluminum to be brought into solution to precipitate insoluble phosphates. The curves began to rise when the clays were theoretically

magnesium saturated because insoluble magnesium phosphates were beginning to be precipitated at the high pH values produced. The depressive effect of magnesium was reduced in the treated clays, but the trend was in the same order.

The addition of increments of sodium to calcium clays (Figs. 3 and 4) greatly reduced their adsorptive power. As the amount of sodium was increased, the amount of active calcium decreased and the hydrolysis of iron or aluminum phosphates increased. The phosphate anion adsorption decreased also because of the very alkaline conditions. The extremely alkaline conditions produced would cause calcium, iron, and aluminum phosphates to become more soluble. When magnesium was added instead of sodium, the reduction in adsorption of phosphates was not as pronounced but there was a distinct reduction in the untreated clays (Fig. 3) and a less distinct reduction in the treated clays (Fig. 4). The pH values were raised slightly by the addition of magnesium; hence, the iron and aluminum phosphates were probably hydrolyzed to a greater extent. Magnesium phosphates that may have been formed were more soluble than the calcium phosphates under these conditions.

Addition of increments of sodium to magnesium clays greatly reduced their power to adsorb phosphates. The pH values were raised higher by each additional increment of sodium and consequently more iron and aluminum were precipitated from solution and the phosphates came into solution. Anion adsorption was probably prohibited by the very alkaline conditions produced.

The adsorption of phosphorus by untreated clays saturated with calcium, sodium, and magnesium in equal amounts (Fig. 5) was due primarily to the precipitation of insoluble calcium and magnesium phosphates since the pH values were above 7.0. Practically the same situation existed when the clays were saturated with hydrogen, calcium, and sodium except that no magnesium was present and the pH values were slightly lower. Apparently there was some $Ca_3(PO_4)_2$ precipitated, some anion adsorption, and some iron and aluminum precipitation. When the base exchange complex was saturated with hydrogen, calcium, and magnesium, the precipitation was apparently due almost entirely to iron and aluminum precipitation and to anion adsorption since the suspensions generally were too acid for calcium precipitation to occur. The samples saturated with hydrogen, sodium, and magnesium failed to adsorb a significant amount of phosphorus. The pH values were too high for any form of adsorption to occur. A conclusive explanation in clays of this type is not plausible because of differential adsorption of cations by the exchange complex of the clays.

INFLUENCE OF FREE Fe_2O_3 AND Al_2O_3 ON PHOSPHORUS ADSORPTION

The work reported herein verifies the belief of many investigators in that it points to the fact that the iron and aluminum oxides are very important in controlling phosphate solubility. The data presented in Table 2 are typical of the results obtained which show the contrasting amounts of phosphorus adsorption by clays that

have had their free iron and aluminum oxides extracted and those that have not been so treated. The removal of phosphorus from solution by the untreated hydrogen-saturated samples represented in Table 2 must be attributed almost entirely to adsorption by iron and aluminum oxides. This conclusion seems well justified since there were no cations present in the exchange complex that might precipitate insoluble phosphates.

The variation in adsorption between the treated and untreated clays must, in most cases, be attributed primarily to adsorption by iron and aluminum oxides. A comparison of the graphs in Figs. 2, 4, and 6 with those in Figs. 1, 3, and 5, respectively, show the general decreases in phosphorus adsorption by the treated clays. In most of the treated and untreated samples, the pH values were at a level that would permit attributing the major portion of increased adsorption by the untreated clays to adsorption by iron or aluminum oxides.

SUMMARY

A study was made of the effect of iron and aluminum oxides, pH, and the degree of hydrogen, calcium, sodium, and magnesium saturation of the exchange complex upon the adsorption of phosphorus by Decatur, Hartsells, Houston, Norfolk, and Cecil clay material. The clays, obtained by the sedimentation process, were each divided into two portions; one portion was electrodialyzed to remove all mobile ions and the other portion was treated to remove its free oxides of iron and aluminum and amorphous silica before being electrodialyzed. The electrodialyzed clays were treated with various cations in order to produce various degrees of base saturation. They were then used in adsorption studies in which 1 gram of each clay was placed in 100 cc of solution containing 100 p.p.m. P. The samples were agitated frequently and after standing for 2 days the pH and phosphorus contents of the supernatant liquid were determined. The results of the investigation may be summarized as follows:

1. Treatment of the clays to extract their free sesquioxides decreased the base exchange capacity of those which were high in organic matter, but not appreciably of those which were low in organic matter and high in free iron and aluminum oxides.

2. The amount of phosphorus adsorption by the untreated clays saturated with the various cations varied from highest to lowest in the order of hydrogen, calcium, magnesium, and sodium, respectively, while the treated clays varied from highest to lowest in the order of calcium, hydrogen, magnesium, and sodium. In every instance, the partially base-saturated clays adsorbed less phosphorus than the completely saturated clays.

3. The Cecil and Houston clays were the only treated clays that adsorbed a considerable amount of phosphorus when saturated with hydrogen. None of the clays when saturated with sodium adsorbed a significant amount of phosphorus, due to the solvent action of NaOH resulting from hydrolysis and formation of sodium phosphates. Cecil clay was particularly outstanding in this respect

when the exchange complex was saturated with three cations in equal amounts.

4. Extraction of the free iron and aluminum oxides from the clays caused a reduction in the phosphorus adsorptive capacity in practically every case. Considerable evidence is presented to show that various agencies were active in the adsorptive processes. It appears that the adsorption within the pH range of most acid soils was due primarily to the formation of insoluble iron and aluminum phosphates, and in the pH range of neutral to alkaline soils containing considerable available calcium to the precipitation of tricalcium phosphate.

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NATURE OF ORGANIC MATTER IN WESTERN WASHINGTON PRAIRIE SOILS AS INFLUENCED BY DIFFERENCES IN RAINFALL[1]

R. H. Fowler and L. C. Wheeting[2]

THE result of the integration of the several factors of climate, particularly temperature and rainfall, is normally well expressed by the amount and character of the soil organic matter which develops in different environments. In 1928, Jenny (4)[3] found a relationship between mean annual temperature and the amount of nitrogen in prairie and chernozem soils of the Great Plains region. The lower the mean annual temperature the higher was the nitrogen content of the soil. He also found that the ratio of carbon to nitrogen increased with decreasing mean annual temperature. There has been little opportunity, in this country, to study the influence of variations in rainfall on the character of the organic matter of prairie soils because of the difficulty in finding areas with relative uniformity in all climatic factors except precipitation.

On the north side of the Olympic Peninsula of Washington, however, from Cape Flattery on the west to Discovery Bay on the east is a region of relatively uniform mean annual temperature and relative humidity, but the rainfall varies from more than 120 inches on the west to about 15 inches on the east. Throughout this area several natural and extensive non-forested areas have developed. Samples of the surface soils from such areas provided an opportunity to study the effect of wide variation in rainfall on the nature of the soil organic matter. The results of the examination of these soils from five localities form the basis for this paper.

CLIMATE

Mean annual rainfall for the localities from which soil samples were obtained on the Olympic Peninsula are indicated in Fig. 1. Data showing the monthly variation of both rainfall and temperature are given in Table 1.

COVER

The study area is heavily and almost completely forested with Douglas fir (*Pseudotsuga taxifolia*) with occurrences of western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), and Sitka spruce (*Picea sitchensis*). In zones of heaviest rainfall, hemlock and cedar predominate, but Douglas fir is the dominant species throughout the remainder of the moisture range. Sitka spruce is identified with the others along the immediate coast line especially in the heavy fog belt.

[1]Contribution from the Soil Survey Division, Department of Conservation and Development, State of Washington, and Washington Agricultural Experiment Station, Pullman, Wash. Received for publication July 15, 1940.

[2]Soil Surveyor and Supervisor of Division, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 23.

TABLE 1.—*Climatic data giving monthly distribution and mean annual rainfall and temperature of points on the Olympia Peninsula, Washington.**

Location	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean annual
					Rainfall, Inches								
Clallam Bay	13.43	9.11	9.35	5.64	3.47	3.13	1.61	1.56	3.30	7.32	9.89	13.17	80.98
Forks	18.15	14.62	11.98	8.36	5.54	4.32	1.54	2.05	5.46	12.06	18.16	18.06	120.30
La Push	11.48	8.97	7.39	7.98	3.38	3.73	1.77	1.42	4.77	5.72	10.70	12.60	79.91
Port Angeles	4.54	3.29	2.20	1.49	1.18	0.89	0.48	0.71	1.48	2.36	3.96	4.78	27.36
Pysht	10.56	8.13	6.29	4.49	2.56	2.59	0.80	0.91	4.13	5.87	9.23	11.80	67.36
Sequim	2.13	1.57	1.43	1.06	1.01	0.92	0.44	0.66	1.07	1.43	2.48	2.62	16.82
Tatoosh Isl	11.83	9.45	7.85	5.63	4.00	3.20	1.54	2.02	4.68	8.13	11.93	13.36	83.62
					Temperature, °F								
Clallam Bay	37.4°	38.8°	42.6°	46.6°	50.0°	54.8°	56.2°	57.4°	54.0°	49.4°	43.0°	39.8°	47.6°
Forks	38.0°	40.5°	41.2°	47.1°	52.3°	56.3°	59.4°	60.8°	56.8°	51.1°	43.9°	39.6°	49.2°
Port Angeles	37.3°	39.0°	41.8°	45.5°	50.3°	54.5°	57.1°	57.8°	53.9°	48.2°	42.6°	39.1°	47.3°
Sequim	37.6°	39.2°	42.2°	47.2°	51.3°	56.4°	58.8°	60.0°	55.9°	49.4°	42.5°	38.0°	48.2°
Tatoosh Isl	41.2°	41.0°	42.9°	46.1°	49.6°	53.0°	55.1°	55.3°	53.0°	49.9°	45.9°	43.9°	47.1°

*Data from U.S.D.A. Weather Bureau.

Under these conditions of ideal forest climate, and midst dense forests, several unforested areas occur, sporadically placed. These consist of the Quillayute Prairie, occurring on the Quillayute Indian reservation about 5 miles northwest of Forks and occupying about 3,000 acres; the Little Prairie about 2 miles north of the Quillayute, about 600 acres; the Forks Prairie at Forks, which is similar to the Quillayute and covers about 2,500 acres; the Shuwah Prairie about 12 miles northeast of Forks, having about 200 acres; the Beaver Prairie about 20 miles northeast of Forks and covering approximately 300 acres; and the Sequim Prairie at Sequim, covering about 2,000 acres.

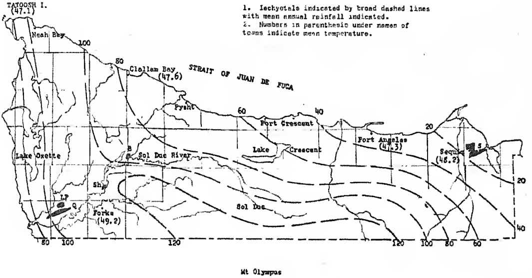

FIG. 1.—Climatic factors and sampling areas of prairie soils, Clallam County, Olympic Peninsula, Washington.

The prairies fall approximately in the following rainfall groups: Quillayute and Little Prairie between 115 to 125 inches; the Shuwah between 95 to 110 inches; the Beaver between 80 to 95 inches; and the Sequim at about 15 inches. Under these climatic conditions the Sequim Prairie is the only one that could be expected to establish and maintain itself as a true prairie under mixed grass and herbaceous cover. Smith (6) believes that they are "accidental or artificial rather than natural, transitory rather than permanent." In every case the parent material and moisture conditions are the same as those found in the adjacent forest.

The prairies in the higher rainfall districts have a dense cover of bracken fern (*Pteridium aquilinum pubescens*) which grows to a height of 6 feet or more, but the Sequim Prairie has a grass and herbaceous cover. In Fig. 2, two views are given of the western prairies in which the dense fern cover and forested background are well illustrated. Perhaps these prairies originated from burns either accidentally or purposely and, once established, were maintained by continued burning. In Fig. 2, B, the unforested area on the hill in the background is also prairie soil similar in all respects to that on the more level foreground. These "tongues" of the prairie on the slopes give the impression that the prairies originated from burns.

Wheeting (10) points out that microscopic examination of the soils show no charcoal which should be present had they been burned annually. Another possibility is that the bracken fern which had taken over the ground following the first burn built up a soil condition

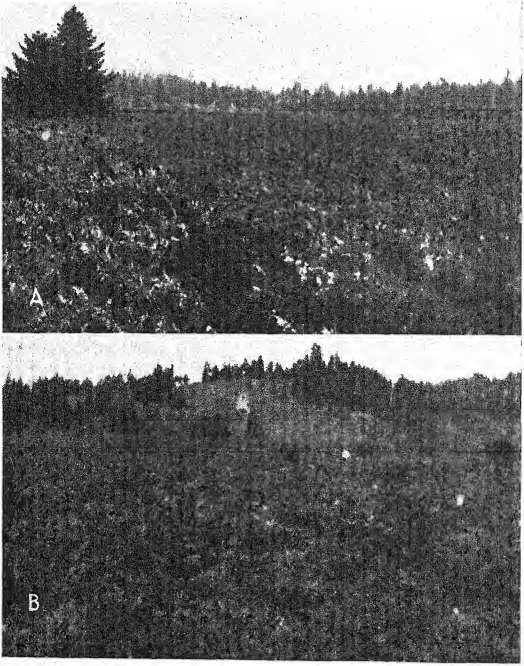

FIG. 2.—Comparison of the dense bracken fern cover of the prairies in contrast with the normal heavy forests of the region. A, Quillayute Prairie; B, Little Prairie. Note the non-forested area on the hill in B which has the same black soil as the more level parts of the prairie in the foreground.

suited particularly to itself and, with the help of the dense shade it affords, has been successful in prohibiting the re-establishment of a forest. It is only after abandonment of cultivated fields that forest encroachment takes place, but this is only where the bracken fern has

been markedly thinned and the area has either been cropped or grazed for some time. In one instance a mature stand of hemlock has established itself on a black soil similar to the Quillayute, indicating that possibly this area had been a prairie which had been invaded by the forest a long time ago. In any event, it is surprising to find prairies maintaining themselves under conditions so favorable to forest growth.

It has been suggested that these unforested areas should be designated forest meadows or heaths rather than prairies. Two requirements for such designations are missing in the areas here described. First, no true heath plants form a part of the vegative cover, and second, the poor drainage conditions associated with forest meadows is lacking.

Warming (9) describes a plant association called "Fern Heath," but places it under "Formations on Waste-land," where xerophytic conditions prevail. In this regard also, the western Washington areas are of quite different character. While it is true that the term prairie generally assumes the presence of a grass vegetation, it is also commonly employed for designating non-forested soils with no lime accumulation in the profiles. It is in the latter sense that the term is used in this paper and in view of the use of the term locally to designate the unforested areas, there should be no serious objection to its use. It should be clearly understood, however, that these prairies are not developed on recently cut-over forest land, but are natural formations of considerable age as indicated by the large accumulations of organic matter.

SAMPLE DESCRIPTIONS

Of each prairie area, two samples were taken, the first including only the immediate surface layer and the second the main horizon of dark-colored soil. The exact thickness of each layer sampled is indicated in Table 2. The surface samples in all cases were dark brown in color and contained much raw organic matter, consisting mainly of leaves and stalks of bracken fern. The sample of the second horizon was dark brown to black in color and the organic matter showed more decomposition but still contained many root stalks of the fern. The Sequim Prairie soil was not as dark colored as the others nor was the upper organic layer as deep. This may not always mean less organic accumulation, however, since Daniel and Wright (3) point out that color is more affected by the nature of the organic matter than by the amount. The subsoils of all were similar to the adjacent forested soils and were all well drained and well aerated. The subsoil of the Quillayute Prairie consists of a straw-yellow-colored silty clay loam or clay to over 6 feet in depth and has a very cheesy consistency. The Little Prairie, Beaver, and Sequim Prairies have permeable gravelly subsoils, while the Shuwah Prairie has developed on what appears to be moderately recent silty river sediments. Detailed descriptions of the entire profile in each case will be found in the soil survey report for Clallam County.

TABLE 2.—*Depth of samples and analyses of the prairie soils indicated.*

Source of soil	Depth of sample, inches	Mean annual rainfall, inches	pH	Sand, per cent	Silt, per cent	Clay, per cent	Organic matter on ignition, %	Organic matter, C×1.72, %	Total C, %	Total N, %	N in organic matter, %	C/N ratio
Quillayute Prairie	0–7	115–125	5.15	24.4	51.8	23.8	27.6	26.7	15.54	0.924	3.45	16.8
	7–18	115–125	5.20	21.7	55.5	22.8	22.2	20.9	12.15	0.667	3.19	18.2
Little Prairie.....	0–5	115–125	4.82	53.3	27.7	19.0	27.6	24.6	14.34	0.982	3.99	14.6
	5–18	115–125	4.93	46.0	32.4	21.6	24.2	20.7	12.06	0.777	3.75	15.5
Shuwah Prairie...	0–6	95–110	4.53	32.3	41.4	26.3	19.7	17.4	10.11	0.734	4.22	13.8
	6–18	95–110	4.56	26.5	44.6	28.9	16.6	14.3	8.47	0.547	3.82	15.5
Beaver Prairie...	0–8	85–95	4.69	38.0	51.0	11.0	33.2	30.6	17.8	1.266	4.14	14.0
	8–18	85–95	4.88	37.0	52.5	10.5	32.2	26.9	15.65	1.101	4.10	14.1
Sequim Prairie...	0–3	15–20	6.62	65.0	24.7	10.3	12.4	9.77	5.68	0.487	4.98	11.6
	3–16	15–20	6.32	65.2	25.1	9.7	11.3	8.58	4.99	0.456	5.32	10.9

ANALYTICAL METHODS

The texture, reaction, and total nitrogen of the soil samples were determined by the Bouyoucos hydrometer method, by the glass electrode method, and by a modified Kjeldahl method, respectively.

The total organic matter was determined in two ways, by ignition in a muffle furnace at red heat (850°C) and by a determination of total carbon by the wet combustion method. To determine the organic matter from the latter, the usual calculation, using the equation carbon $\times$ 1.72 equals organic matter, was made.

Fractionation of the organic matter was made by means of an adaptation of the Waksman and Stevens (7) method in which the following modifications are the most important: (a) Air-dry soil was ground and sieved through a 100-mesh screen and samples taken on the oven-dry basis to equal approximately 10 grams of organic matter. This was extracted with benzene and alcohol for 12 hours on a steam bath under reflux condensers, filtered through a Buchner filter, the filtrate evaporated to dryness, the last 50 cc in a weighing bottle, and the total carbon determined on the residue. This yielded the alcohol-benzene fraction consisting of fats, waxes, and resins. (b) The treated soil from (a) was placed in a Florence flask, the volume made up to 300 cc with distilled water, and placed on a steam bath for 3 hours under reflux condensers. The solution was then filtered off, made acid with HCl, evaporated, and the total carbon determined on the residue. This gave the fraction designated as water-soluble material. (c) The soil from treatment (b) was dried at 60°C for 24 hours, weighed, and samples taken to equal approximately 1 gram of organic matter. These were placed in 500-cc Florence flasks and enough 80% H_2SO_4 added to make a heavy paste. This was allowed to stand for 2½ hours at room temperature, then 15 times as much distilled water as acid added and the diluted extract was heated for 5 hours in flowing steam. This mixture was filtered on a Buchner filter and the precipitate washed thoroughly with water. The filtrate was made up to a definite volume from which an aliquot was evaporated and the total carbon determined. This procedure yielded the fraction called "hemi-celluloses and celluloses." Two samples were taken of the residue from (c) and carbon determined on one of these in order to obtain values for the "lignin-humus" and crude protein together. Total nitrogen was determined on the other sample from which crude protein was computed by use of the 6.25 factor.

In using carbon as the determined part of each fraction, any nitrogenous compounds made soluble by the different treatments were thus determined with the fractions. From the carbon in the "lignin-humus" complex and the nitrogen of the "crude protein," the amount of "lignin-humus" organic matter is determined by the use of the conventional factors, 1.72 times carbon equals organic matter and 6.25 times nitrogen equals crude protein, and subtracting the crude protein from the "lignin-humus" determination. The total protein of the soil as originally determined in each case was nearly double that of crude protein determined after all treatments had been completed. Thus, about one-half of the protein and other nitrogenous compounds were included with the other organic matter fractions.

Waksman and Stevens (8) found that 80% H_2SO_4 followed by boiling with a 5% solution of H_2SO_4 for 5 hours made soluble about 30% of the protein, this after a previous treatment with HCl had also made about 30% soluble, showing that between 50 to 60% of the protein was made soluble by treatment with acids. As only about 50% of the nitrogenous compounds need be accounted for in the other fractions, it is safe to presume that all (excepting possibly negligible quantities on alcohol-benzene and water-soluble groups) were determined with the

celluloses. Thus, the organic matter of the cellulose group less the difference between total protein and crude protein should give approximately the amount of hemi-celluloses and celluloses of the soil and also account for all nitrogenous compounds.

In using Van Bemmelen's (2) factor 1.72 and the factor 6.25, it is presumed that the organic matter consists of 58% carbon and that the nitrogenous compounds contain 16% nitrogen. Waksman and Stevens (8), Alexander and Byers (1), and others have shown that the carbon content of the organic matter varies considerably from 58% and also that each fraction has a different percentage of carbon, cellulose having 44% and lignin over 60%. From the weights of the water-soluble fraction residue and carbon determined, it was found that this fraction had about 40% carbon and similarly the alcohol-benzene fraction contained about 59% carbon. Therefore it seems that no single factor can be used without introducing considerable error, but for comparative purposes the factor 1.72 was used throughout the determinations.

EXPERIMENTAL RESULTS

TEXTURE AND REACTION OF SOILS

The texture of the soils, depth of sampling, reaction (pH), and the rainfall conditions in which they are located are given in Table 2. The results of the mechanical analyses need little comment except to point out that the soils have a considerable range in texture from a silty clay loam to a sandy loam. No relation exists between the rainfall and the texture of the soils. It is interesting to note that these soils, except the Sequim, which have developed under a rainfall of over 80 inches, show no definite increase in clay content in the second horizon; the Little Prairie and Shuwah Prairie show a slight increase, while the Quillayute and Beaver Prairies show a slight decrease in clay content with depth. This is found to be generally true throughout this region, indicating an almost total absence of eluviation processes.

A striking uniformity in the depth of the dark-colored soil of each prairie is shown, indicating that the depth of the soil is less affected by the amount of rainfall than by the normal depth of penetration of the roots of the fern, expecially when the rainfall is sufficient for a luxuriant plant growth. The soil reaction under the higher rainfall conditions is more strongly acid than that under the lower rainfall. In this respect, the usual relationship between the reaction and the amount of rainfall appears to hold.

ORGANIC MATTER

Several things are brought out in studying the nature of the organic matter. The results of the analyses are also given in Table 2. Except for the Sequim soil, all are extremely high in organic matter; in fact on the basis of some standards they would be considered as muck soils. The prairies, however, are well drained and well aerated; the organic matter is not an accumulation caused by excessive amounts of water prohibiting decomposition by biological forces as in the cases of peats and mucks. The organic matter is derived almost completely from the bracken fern which contributes a very tough resistant

material. In all soils the "lignin-humus" complex is abundant, constituting approximately one-half of the total organic matter.

The relationships between the two methods of determining the organic matter content, e. g., by the wet combustion method ($C \times 1.72$) and by the direct ignition method, show that in all cases the percentage of organic matter by the ignition method is higher than that obtained by the wet combustion method. This amounts to a maximum difference of 5.3% in the lower horizon of the Beaver Prairie soil and 0.9% in the upper horizon of the Quillayute soil, the average difference for all soils equalling 2.65%. As many observers point out, the ignition method is inaccurate in that water tenaciously held by the soil colloids is also driven off and recorded with the percentage of organic matter. In comparing the differences found here, however, no definite relation appears between the heavier and lighter textured soils as might be expected if the differences were due entirely to the chemically combined water. Arbitrary use of the factor 1.72 for all soils may be a source of some error in the indirect determinations.

The carbon-nitrogen ratios and the percentages of nitrogen in the organic matter present the most interesting correlations with mean annual rainfall. There is a definite tendency for a narrowing of the ratio with a decrease in mean annual rainfall. Averaging the values obtained with two samples of each soil, the Quillayute and Little Prairie have C/N ratios of 17.5 and 15.0, respectively, or an average value of 16.25 for the high rainfall belt; the Shuwah, under less rainfall averages (14.5; the Beaver, under still less rainfall, 14.05; and the Sequim, under the least rainfall, 11.8. Thus with a decrease of mean annual rainfall from 120 inches to 15 inches, a narrowing of the C/N ratio occurs from 16.25 to 11.8.

Leighty and Shorey (5) found from a study of a large number of samples taken from various points in the United States that there is a wide variation in C/N ratio but that the average is close to 10:1. Jenny (4) found a variation of the C/N ratio from 15.1 to about 9.1 in relation to the temperature from northern to southern United States; the cooler the temperature the wider was the ratio.

There is also a definite relation between the total nitrogen of the organic matter and the amount of rainfall. This was indicated in the study of the C/N ratios but is more clearly shown by averaging the result from the Quillayute and Little Prairie to obtain a single value for the highest rainfall group. The results show that under 120 inches of rainfall the percentage of nitrogen in the organic matter is 3.58; under 95 to 110 inches, 4.02; under 85 to 95 inches, 4.12; and under 15 to 20 inches, 5.15. A correlation exists between the mean annual rainfall and the amount of nitrogen in the organic matter of these soils, the amount of nitrogen increasing with decreasing amounts of rainfall. Jenny (4) found a mathematical relation existing between the total nitrogen of the soils and the mean annual temperature, the nitrogen decreasing exponentialy as the temperature increases. It is interesting to find that a similar relationship exists in these prairies between nitrogen content of the organic matter and mean annual rainfall under uniform temperature conditions.

FRACTIONATION OF THE ORGANIC MATTER

The proximate chemical compositon of the soil organic matter computed on the basis of the total soil organic matter is summarized in Table 3. In studying this table, it becomes clear that the composition of the organic matter of these soils varies considerably, but no striking relationships between any one fraction of the organic matter and the amount of rainfall occur, except in the case of the nitrogenous complexes. This would be expected in view of the carbon and nitrogen relationships previously discussed. The "lignin-humus" complex consititutes by far the largest fraction and together with the nitrogenous complexes makes up between 70 to 80% of the total organic matter.

TABLE 3.—*Proximate chemical composition of organic matter in western Washington prairie soils.*

Soil	Alcohol-benzine	Water soluble	"Hemicelluloses-celluloses"	"Lignin-humus"	Nitrogenous complexes	Sum of fractions
Quillayute Prairie	2.10	0.94	15.95	51.60	21.90	92.49
	1.74	0.86	15.63	59.80	19.90	97.93
Little Prairie.....	2.35	1.27	13.95	53.30	24.90	95.77
	2.03	1.03	17.15	54.00	23.50	97.71
Shuwah Prairie..	1.98	1.32	14.65	54.10	26.40	98.45
	2.07	1.24	15.73	57.90	23.70	100.64
Beaver Prairie...	2.88	1.25	16.90	49.50	25.84	96.37
	2.66	1.03	15.63	52.80	25.62	97.74
Sequim Prairie...	3.50	2.17	10.34	52.50	31.10	99.61
	3.09	1.42	11.53	44.60	33.30	93.94

The correlation existing between these two fractions closely parallels that observed between total carbon and nitrogen. Approximately one-half (53.0%) of the total organic matter is made up of the "lignin-humus" complex alone. The percentage of water-soluble organic matter, although small in all cases, shows definite increases in amount with a decrease in mean annual rainfall. In the Sequim surface soil under approximately 15 inches of rainfall annually, the amount of water-soluble material is more than double that of the Quillayute surface soil under approximately 120 inches of rainfall. The rainfall in this case probably plays an important role in leaching out of the more soluble material from the soil even though there is generally less of it in the lower surface sample from each soil.

The alcohol-benzene fraction is present in quite uniform amounts in all soils, although the Sequim soil contains a slightly larger quantity. The percentages of the acid-hydrolyzable constituents, "hemicelluloses and celluloses," are also erratic in the relation to the rainfall, the Sequim soil containing the lowest quantity. The difference in vegetative cover existing between the Sequim soil and the others may also be a significant factor in this connection.

SUMMARY

Under climatic conditions highly favorable for forest growth in western Washington several natural prairies exist. Such areas afforded an opportunity for the study of the differences in the nature of soil organic matter which has developed under conditions of uniform temperature and humidity but under a wide range in mean annual rainfall. It was found that the composition of the organic matter varies greatly in the different soils, that certain fractions are more affected by variations in rainfall than others, and that the nitrogenous complexes together with the "lignin-humus" complex constitute the major portion of the soil organic matter.

The C/N ratio and total nitrogen in the organic matter were found to vary in relation to the mean annual rainfall; the C/N ratio is wide under high rainfall and narrows under low rainfall; the nitrogen content of the organic matter is low under high rainfall and increases with decreasing amounts of rainfall. The water-soluble materials are least abundant in the soils developed under heavy rainfall.

No clear-cut relationships between mean annual rainfall and other fractions of the soil organic matter are evident.

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BASE EXCHANGE CAPACITY DETERMINATION OF SOILS BY MEANS OF A RAPID COLORIMETRIC COPPER METHOD[1]

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A KNOWLEDGE of base exchange capacity of soils is of considerable help in diagnosing lime and fertilizer needs. Greater application of this factor in this connection and in classifying soils has been limited in the past because of the rather laborious methods employed in its determination. Most of the methods that have been used are modifications of those devised by Gedroiz (6)[3] in which the exchangeable cations of the soil are replaced by the cation of a neutral salt solution with which the soil is leached. The exchange capacity is then determined by measuring the quantity of cation adsorbed from the salt solution by a definite amount of soil. Many modifications of the methods of Gedroiz have been made, but all of these require the complete removal of the excess of leaching reagent from the soil, which requires considerable time and thus has been a factor in limiting the use of these methods.

Thus there exists a growing demand for a more rapid and a less laborious method for determining the base exchange capacity of soils (2). It was the purpose, therefore, of this investigation to devise a simple and rapid method for determining the base exchange capacity of soils.

The use of rapid chemical tests on both plants and soils for detecting deficiencies of certain essential elements and for estimating fertilizer needs and lime requirements has increased greatly in recent years. The soil tests have been confined largely to determinations of pH and available potassium and phosphorus; however, in order to aid the interpretation of these tests in certain cases, other tests have also been made. It has long been known that the lime requirement of any soil is dependent upon two independent and variable factors—the original pH of the soil and the buffer capacity or exchange capacity of the soil. The pH of the soil is quite easily determined by existing quick methods, but the buffer capacity often has been estimated from the physical properties of the soil such as texture and abundance of organic matter.

Recent work by Jenny and Ayres (7) and by Bray (4) has shown that the availability to the plant of exchangeable ions, such as potassium, is dependent upon several factors. Jenny and Ayres state that the most important factors concerned with the availability of an exchangeable ion are the degree of saturation with the ion in question and the nature of the complementary ions that are associated with it in the base exchange complex. These findings indicate that the de-

[1]Contribution from the Department of Agricultural Chemistry, Purdue University, Lafayette, Indiana. Also presented at the annual meeting of the Society held in Chicago, Ill., December 4 to 6, 1940. Received for publication August 14, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 36.

termination of the availability of replaceable potassium can be aided by a knowledge of the exchange capacity of the soil.

EXPERIMENTAL

A great majority of the so-called "quick" soil tests are made colorimetrically for convenience and speed. It was hoped, therefore, that a rapid colorimetric method for base exchange capacity could be devised which would give satisfactory results for use in conjunction with other tests for estimating lime and fertilizer needs of soils. It seemed logical that if a weighed amount of soil were shaken with a measured quantity of a solution of known salt concentration containing a colored cation and if the suspension were then filtered, that the decrease in color intensity of the filtrate could be used as a quantitative measure of the base exchange capacity.

Of the elements which form colored cations, copper (cupric) was selected as the most logical to use in the present case because its salts form stable, highly colored solutions which are easily standardized. Furthermore, copper forms a stable, highly colored complex-ion with ammonia which can be used for its quantitative determination in very low concentrations (5); and, both its small ionic radius and its positive valence of two make it very effective as a replacing ion in base exchange reactions.

The selection of cupric acetate as the salt to be used was based on the observation that the acidity of its solutions was much less than solutions of the sulfate, nitrate, or chloride containing equivalent quantities of copper. The pH of a 0.2 normal cupric acetate solution was 5.4 while 0.2 normal solutions of the other salts gave pH values from 3.0 to 3.2. Cupric nitrate has been used successfully as a reagent for determining the base exchange capacity of soils in a leaching method reported by Fieger, Gray, and Reed (5). In the method to be presented here the use of cupric acetate should be preferable to the use of the cupric salts of the stronger acids because the acetic acid formed by the exchange reaction with acid soils is only slightly ionized, thus allowing the displacement to go more nearly to completion.

Another advantage of the cupric acetate solution over solutions of other cupric salts was its more intense blue color; however, all of these salts gave solutions of the same color intensity when they were treated with an excess of ammonia to form the cupra-ammonio ion. The more intense blue color of the cupric acetate solution was found to be advantageous because one could easily ascertain when a slight excess of reagent had been added to the soil by the light bluish green color of the supernatant solution. If a cupric sulfate solution were used, an extremely large excess of reagent would need to be present before there would be any indication from the color of the supernatant solution that an excess had been used.

Although a bluish green color remained in the solution after a weighed quantity of soil had been treated with a slight excess of cupric acetate and then filtered, it was not of great enough intensity to be used conveniently for the colorimetric determination of the copper

present. By mixing a measured quantity of this filtrate with a definite quantity of ammonium hydroxide to form the cupra-ammonio complex ion, the small amount of copper gives a solution having a very intense blue color that can be used as a quantitative measure of the copper present. This color was found to be stable for a period of three months and doubtless would be stable indefinitely so long as an excess of ammonia is present. Permanent standards containing 0.53 to 1.06 grams of copper per liter were found to possess stability and to have a sufficient range of color intensity to allow their use in the colorimetric determination of base exchange capacity. Muller (9) reported that solutions contining 1 gram or less of copper per liter as the cupra-ammonia ion followed Beer's law.

EFFECTIVENESS OF CUPRIC ACETATE IN BASE EXCHANGE REACTIONS

Samples of electrodialized bentonite and of soil colloids were used to test the effectiveness of cupric acetate as a reagent in base reactions. The soil colloids used were isolated from a subsurface sample of Miami silt loam and from a surface sample of muck. The base exchange capacities of these colloidal suspensions were determined from the potentiometric titration curves obtained when measured volumes of the suspensions were treated with increasing quantities of saturated calcium hydroxide. The curves obtained showed a maximum deflection at pH 8.0 in all cases; therefore, the number of M.E. of base required to adjust the reaction of each suspension representing 100 grams of colloid to pH 8.0 was taken as the exchange capacity of the suspension.

Samples of the electrodialized colloids were treated with quantities of cupric acetate solution equivalent to 1.0, 1.2, 1.4, 1.6, and 2.0 times the exchange capacity of the colloid at pH 8.0. Baver (1) has used the term symmetry to designate that the M.E. of cation added were equal to the exchange capacity of the colloid and this term is used with the same meaning here. The suspensions which had been treated with various symmetry concentrations of cupric acetate were diluted to equal volumes and mixed thoroughly to insure complete reactions. The dilute suspensions were centrifuged and the supernatant solutions were analyzed for copper. The number of M.E. of copper sorbed by 100 grams of colloid from solutions containing various symmetry concentrations of copper was determined and the percentage saturation at various symmetry concentrations was calculated by dividing the M.E. sorbed by the exchange capacity of the colloid. The results obtained are given in Table 1.

The data presented in Table 1 indicate that copper is sorbed by soil colloids with considerable energy when it is in combination with the acetate ion. It is also apparent from these data that the symmetry concentrations of copper for the reaction should be close to 2.0 to insure a nearly complete reaction between the cupric acetate and the base exchange complex.

SAMPLE SIZE, DILUTION, AND EQUIPMENT

The sample weight, the volume of reagent, and the aliquot of filtrate taken for analysis were all selected to conform with the usual

TABLE 1.—*Amounts of copper sorbed by electrodialized colloids from various symmetry concentrations of cupric acetate.*

Electrodialized colloid*	Base exchange capacity at pH 8.0, M.E. per 100 grams of colloid†	M.E. of copper sorbed per 100 grams of colloid and the percentage sorption from various symmetry concentrations									
		1.0 symm. conc.		1.2 symm. conc.		1.4 symm. conc.		1.6 symm. conc.		2.0 symm. conc.	
		M.E. Cu sorbed	% saturation	M.E. Cu sorbed	% saturation	M.E. Cu sorbed	% saturation	M.E. Cu sorbed	% saturation	M.E. Cu sorbed	% saturation
H-Bentonite....	84.0	52.2	62.0	53.0	63.0	56.8	67.6	64.4	76.6	67.6	80.3
H-Miami.......	66.6	40.8	62.0	48.9	74.2	52.7	80.0	60.0	91.0	66.0	100
H-Humus.......	379.0	283.0	74.6	310.0	81.6	335.0	88.4	344.0	91.1	376.0	99.1

*The term H-Humus refers to the electrodialized colloid isolated from a muck soil, H-Miami to the electrodialized clay isolated from Miami silt loam, and H-Bentonite to the electrodialized bentonite.

†The base exchange capacity at pH 8.0 was taken from the titration curves obtained when the colloids were treated with increasing quantities of saturated calcium hydroxide solution.

quantities used in the various chemical quick tests now employed for analyzing soils. Most of the quick tests use sample volumes rather than sample weights for the sake of convenience; however, the base exchange capacity of a soil is usually expressed on the basis of 100 grams of soil and, therefore, it seemed logical to use a definite weight of soil rather than a measured volume. The sample weight selected was 5 grams of air-dry soil or an equivalent quantity of moist soil.

Calculations showed that a 5-gram sample could be used satisfactorily with a 0.2 normal cupric acetate solution if the final volume of dilution were 20 ml for soils having base exchange capacities of 27 M.E. or less per 100 grams of air-dry soil. For soils having base exchange capacities from 28 to 64 M.E. per 100 grams, the final dilution would be 40 ml for the same quantity of soil. These final dilutions allow for the addition of sufficient reagent to insure the presence of at least 1.5 times the symmetry concentration of copper for all soils. The calculations were based on the use of a 5-ml aliquot of the filtrate obtained by treating 5 grams of soil with a measured quantity of the cupric acetate and on the subsequent preparation of the unknown color solution obtained by treating the aliquot with 2.5 ml of dilute ammonium hydroxide. By measuring quantitatively the amount of copper in the filtrate and deducting this from the amount added originally, one could calaculate the quantity of copper sorbed by 100 grams of soil—its exchange capacity.

The use of a 5-ml aliquot of filtrate and its subsequent dilution to 7.5 ml with ammonium hydroxide gave colored solutions of cupraammonio ions which followed Beer's law and had color intensities which were of a great enough range to allow accurate visual comparison with permanent standards stored in vials 2 cm in diameter.

The equipment needed for the determination consists of the following: Two 10-ml graduated pipets for measuring the reagent and the distilled water; a 50-ml graduated cylinder or test tube to be used for the chemical reaction between the soil and the reagent; and a set of funnel top vials 2 cm in diameter and graduated at 5 ml and 7.5 ml to be used in filtering and comparing the colors of the test solutions with those of the permanent color standards.

INFLUENCE OF ACIDITY OF CUPRIC ACETATE SOLUTION

The base exchange capacities of several representative soils were determined by using both cupric acetate and cupric sulfate solutions. Both of these solutions were 0.2 normal in cupric ions but varied considerably in their active acidity, the pH of the cupric acetate being 5.4 and that of the cupric sulfate 3.2. When the soils were high in exchangeable hydrogen, cupric acetate gave values for the exchange capacities which agreed very well with those obtained by the ammonium acetate (11) and calcium acetate (8) leaching methods; however, when the amount of exchangeable hydrogen was low the values obtained with cupric acetate were higher than those found by the leaching methods. When cupric sulfate was used as the reagent instead of cupric acetate, the values obtained for soils high in exchangeable hydrogen were much lower than those found by the leach-

ing methods. For soils low in exchangeable hydrogen the values with cupric sulfate agreed very well with those obtained by leaching the soil with ammonium acetate or calcium acetate.

These observations indicated that the sulfuric acid produced by the exchange reaction between cupric sulfate and acid soils prevented a complete displacement of the exchangeable hydrogen and thus the values were low. With cupric acetate the weakly ionized acetic acid produced did not interfere with the displacement of hydrogen from the exchange complex by copper and the values were nearly the same as those obtained by the leaching procedure. When neutral or alkaline soils containing only a small amount of exchangeable hydrogen were treated with cupric acetate, a considerable quantity of the copper was doubtlessly precipitated as the basic carbonate or other basic salts of copper and the values for the exchange capacities were high. Due to the greater acidity of the cupric sulfate solution, the precipitation of basic salts did not take place when neutral or alkaline soils were treated with this solution, and the copper removed from the solution was thus a measure of the sorption of copper by the exchange complex.

By acidifying the cupric acetate solution with acetic acid it was thought that the precipitation of basic salts could be prevented when neutral or alkaline soils were treated, and that the increased acidity would not materially decrease the efficiency of the copper in displacing hydrogen from the more acid soils. Six solutions were prepared to contain cupric acetate and acetic acid in amounts that would give a final concentration of 0.2 normal in cupric ions in all solutions and a variation of acetic acid concentration from 0 to 0.1 normal. These solutions were used to determine the exchange capacities of a number of soils having rather wide variations in both their exchange capacity and exchangeable hydrogen values. The results obtained along with other pertinent data are recorded in Table 2.

The data recorded in Table 2 show that there is a gradual decrease in the exchange capacity values obtained by the copper acetate method with increasing acidity. The solutions containing acetic acid in concentrations of 0.06 and 0.08 normal gave values which correspond reasonably well with those obtained by the leaching methods.

On the basis of these observations a solution was prepared so as to be 0.2 normal with respect to cupric ions and 0.07 normal with respect to acetic acid. The pH of this solution was 4.62, showing that it had an active acidity of somewhat less than 0.0001 normal. Thus, the solution, being well buffered, would neutralize a considerable quantity of basic material and would prevent the precipitation of the basic salts of copper which cause the values with neutral or alkaline soils to be high.

This cupric acetate-acetic acid solution was used for determining the base exchange capacities of several soils representing a rather wide range of exchange capacities. The results obtained are recorded in Table 3.

The data in Table 3 show that the quick method employing the cupric acetate-acetic acid mixture gave values that corresponded well enough for practical purposes with those obtained by the more labor-

ious leaching methods. The soils with unusually high exchange capacities, the sweet muck and acid rifle peat, gave values that varied considerably when the three methods were compared; however, in both cases, the rapid cupric acetate method gave values that were more nearly like those obtained by the ammonium acetate method. This divergence of values was not as great as the differences obtained between the two leaching methods. For the alkaline soils, Nos. 13 and 16, the values by the rapid method were nearly the same as the values obtained by the ammonium acetate method even though a large quantity of free carbonate was present in both samples.

TABLE 2.—*Influence of acidity on the cupric acetate method of determining base exchange capacity.*

Value determined	Exchangeable hydrogen, M.E. per 100 grams of soil		Base exchange capacity in M.E. per 100 grams of soil							
Reagent used	Calcium acetate	Ammonium acetate	Calcium acetate	Ammonium acetate	Cupric acetate containing variable quantities of acetic acid					
Normality of displacing ion	0.2	1.0	0.2	1.0	0.2	0.2	0.2	0.2	0.2	0.2
Normality of solution in acetic acid	—	—	—	—	—	0.02	0.04	0.06	0.08	0.10
pH of reagent	8.0	7.0	8.0	7.0	5.42	5.12	4.90	4.75	4.61	4.48
Soil No. 4	1.5	—	2.1	1.8	5.2	4.4	3.3	2.8	2.6	2.1
Soil No. 8	5.0	1.7	10.0	9.6	12.4	11.8	10.7	10.3	9.7	9.7
Soil No. 10	6.3	3.5	23.7	19.5	21.8	20.8	20.2	20.0	18.1	17.5
Soil No. 13	—	—	—	15.9	19.8	18.5	16.2	16.1	15.1	14.2
Soil No. 765a	2.8	1.7	3.6	2.6	6.6	5.7	4.8	4.5	3.4	3.2
Soil No. 765b	1.3	1.1	1.9	1.6	5.4	5.0	3.6	3.4	3.3	2.8
Soil No. V54a	2.2	0	6.8	6.5	8.0	7.7	7.0	7.0	6.1	5.6
Soil No. V54x	7.9	6.1	12.8	10.6	14.6	13.8	11.9	11.7	9.9	10.0
Soil No. 764	2.1	2.1	5.5	4.9	7.7	7.6	6.4	6.1	5.0	4.6

The variation of the values for exchange capacities of soils obtained by different methods has been studied by Puri and Uppal (10). These investigators reached the conclusion that the only reliable method was one involving the potentiometric titration of the soil and that the various leaching methods gave values that corresponded to arbitrarily selected points on the titration curve.

Bower and Truog (3), in a recent publication, reported that substances with high base exchange capacities show appreciable variation in the values obtained with different bases but that with soils of low exchange capacities these variations become small or negligible. It seems logical to conclude that the results obtained by the rapid cupric acetate method are satisfactory for many practical purposes.

This method should be particularly applicable to studies involving large numbers of soils where more exacting methods could not be employed because of the time involved.

TABLE 3.—*Comparison of the base exchange capacity values of soils determined by the cupric acetate-acetic acid method and leaching methods.*

Soil No.	Base exchange capacity in M.E. per 100 grams of soil		
	Leaching with normal ammonium acetate at pH 7.0	Leaching with 0.2 normal calcium acetate at pH 8.0	Quick method with cupric acetate-acetic acid mixture pH 4.62
1	8.0	9.3	6.4
4	1.8	2.1	2.8
8	9.6	10.0	10.0
10	19.5	23.7	18.6
12	6.5	8.9	7.0
15	6.2	9.0	7.4
V54a	6.5	6.8	6.4
V54b	14.5	15.5	12.4
V54x	10.6	12.8	10.7
V54y	6.8	10.9	10.0
Clermont virgin A_1...........	30.5	44.6	32.4
765a	2.6	3.6	3.4
765b	1.5	1.9	3.0
765c	1.4	1.8	2.6
764	4.9	5.5	6.1
Acid rifle peat	145.0	162.0	130.0
Sweet muck	138.0	170.0	116.0
128	9.7	*	8.0
13	15.9	*	16.1
26	25.6	*	28.2
606-1	8.1	*	7.2

*Not determined.

DETAILS OF THE METHOD

The details of the method which was found to be most satisfactory are given below.

REAGENTS AND EQUIPMENT

Cupric acetate-acetic acid solution.—Dissolve 100 grams of reagent quality cupric acetate, Cu $(C_2H_3O_2)_2.H_2O$, in about 2 liters of distilled water. To standardize the solution add 10 ml of 20% potassium iodide to a 10-ml aliquot of the solution and immediately titrate the liberated iodine with standard sodium thiosulfate. Prepare the cupric acetate-acetic acid reagent by transferring measured quantities of the standardized cupric acetate and of normal acetic acid to a volumetric flask and diluting to volume so that the final solution will be 0.2 normal in cupric ions and 0.07 normal in acetic acid. This solution should have a pH of about 4.6 and should be preserved in a stoppered bottle to prevent changes in concentration.

Dilute ammonium hydroxide.—Dilute 1 volume of concentrated ammonium hydroxide (28% NH_3) to 4 volumes with distilled water.

Permanent color standards.—Color standards prepared from solutions containing definite quantities of copper are preferable to printed color charts since they are stable over a long period of time and give exactly the same colors as are obtained when the colors are developed in the unknown solutions. Standards which follow Beer's law and give a good range of color intensities for visual comparison are prepared by adding 33 ml of the diluted ammonium hydroxide to measured aliquots of the cupric acetate-acetic acid mixture and diluting to 100 ml. Six color standards containing from 0.125 to 0.250 M.E. of copper in 7.5 ml of solution are prepared as shown in Table 4.

TABLE 4.—*Preparation of color standards.*

Standard No.	Copper concentration in M.E. per 7.5 ml	Ml of 0.2 N cupric acetate diluted to 100 ml	Ml of dilute NH_4OH to each 100 ml of solution
1	0.125	8.3	33.0
2	0.150	10.0	33.0
3	0.175	11.7	33.0
4	0.200	13.3	33.0
5	0.225	15.0	33.0
6	0.250	16.7	33.0

Seven and one-half ml of each of these standards were transferred to funnel top vials, after which the vials were stoppered with rubber stoppers to prevent the loss of ammonia. The final volume of dilution of the unknown solutions used in the determination of the base exchange capacities of soils was 7.5 ml and, therefore, these standards could be used for direct visual comparison with the unknown solutions. The unknown solutions were compared with the standard solutions in a specially constructed combination filter rack and color comparator.

Combination filter rack and color comparator.—A combined filter rack and color comparator, illustrated in Fig. 1, was constructed for use in this determination. The top member of the rack has 13 ¾-inch holes on a line 1 inch from the front side and 2 inches apart from center to center. The color standards are placed in alternate holes in an increasing order of concentrations and the unknown solution is placed between adjacent standards for color comparison. It is desirable to fasten a piece of frosted window glass (4 × 26 inches) to the frame about ½ inch back of the standards so as to serve as a good background when comparisons are made.

PROCEDURE

Pipet 5 ml of the cupric acetate-acetic acid solution into a 50-ml graduated cylinder, make to 15 ml with distilled water, add 5 grams of pulverized soil, and shake vigorously with an end to end motion. If an adequate quantity of reagent has been added, as indicated by a slight green color of the supernatant solution, add 5 ml of distilled water to make a total volume of 20 ml of solution, shake again, filter the suspension on a Whatman No. 1 filter paper, and collect exactly 5 ml of the filtrate in a funnel top vial calibrated at both 5 and 7.5 ml.

This amount of reagent is adequate for soils with base exchange capacities below 10 M.E. per 100 grams of soil. If the soil has a base exchange capacity higher than 10 M.E., as shown by the absence of any green color in the supernatant solution, add an additional 2.5 ml of reagent, shake, and observe. If the green color appears, add 2.5 ml of water and filter. When no color appears after this addition of reagent repeat with another 2.5 ml portion and then add 5 ml at a time until the color does appear after shaking.

All quantities of reagents of less than 10 ml require a final volume of 20 ml, while those of 15 to 25 ml require a final volume of 40 ml. The largest quantity of reagent that should be used in this test is 25 ml for a 5-gram sample of soil and this amount of reagent when diluted to 40 ml will measure the exchange capacity of soils having values up to 64 M.E. per 100 grams of soil—an exceptionally high value for ordinary agricultural soils.

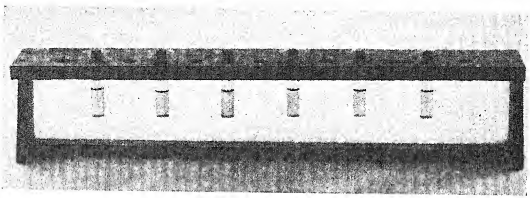

FIG. 1.—Combination filter rack and color comparator.

Five ml of reagent will be adequate for soils having base exchange capacities below 10 M.E. per 100 grams; 7.5 ml for values from 10 to 20 M.E.; 10 ml for values from 20 to 28 M.E.; 15 ml for values from 20 to 40 M.E.; 20 ml for values from 40 to 60 M.E.; and, 25 ml for values from 60 to 64 M.E. If 2.5 grams of sample are used all these values are doubled for any specific volume of reagent. For unusual soils, such as peats and mucks which have exchange capacities higher than 64 M.E. per 100 grams of soil, the same procedure is followed except that a 2.5-gram sample is used and the range of reagent volumes is from 15 to 25 ml for a final dilution of 40 ml.

The 5 ml of filtrate obtained from the filtration of the soil suspension should be carefully measured for greatest accuracy. To the 5 ml of filtrate add 2.5 ml of the dilute ammonium hydroxide, shake, and filter into another funnel top vial. This filtration is required to remove the flocculated aluminum hydrate which, when present, has a tendency to darken the solution. Even though the solution may appear to contain no precipitate, it is absolutely essential that the solution be filtered to assure accurate results.

Compare the unknown colored solution, containing the cupra-ammonio complex ion, with the permanent color standards in the color comparator or with a color standard containing 0.125 M.E. of

copper in 7.5 ml by using a colorimeter. The intensity of the color of the unknown solution should never be less than that of a standard containing 0.125 M.E. of copper in 7.5 ml because this would indicate that less than 1.5 times the symmetry concentration of copper ions had been added to the soil and a nearly complete saturation would not have taken place. On the contrary, the intensity of the solution should not be greater than that of the standard containing 0.250 M.E. in 7.5 ml of solution because the cupra-ammonio solutions do not follow Beer's law above this concentration.

The calculation for the exchange capacity of a soil is based on the number of M.E. of copper sorbed by the quantity of soil used in the test. For the sake of convenience, a table of values was prepared from which the exchange capacity of a soil could be read directly or obtained by interpolation when the volume of reagent, the final volume of the solution, and the concentration of copper in M.E. per 7.5 ml of solution were known. These values are presented in Table 5 for a 5-gram soil sample and for various quantities of reagent.

TABLE 5.—*Calculated values for the base exchange capacities of soils on the basis of a 5-gram sample and variable quantities of reagent.*

		Exchange capacity in M.E. per 100 grams of soil					
Standard used for color comparison*		6	5	4	3	2	1
Copper reagent used, ml	Final dilution, ml						
5.0	20.0	0	2	4	6	8	10
7.5	20.0	10	12	14	16	18	20
10.0	20.0	20	22	24	26	28	—
15.0	40.0	20	24	28	32	36	40
20.0	40.0	40	44	48	52	56	60
25.0	40.0	60	64	—	—	—	—

*The concentrations of copper in M.E. per 7.5 ml for the various standards are given in Table 4.

This table of values can be used conveniently with either the permanent color standards or the colorimeter values. If the colorimeter is employed in the determination, it is only necessary to calculate the number of M.E. of copper in 7.5 ml of the unknown solution and then read the exchange capacity of the soil from the table.

DISCUSSION

The method developed in this research for the determination of the base exchange capacities of soils gave values which agreed satisfactorily for practical purposes with those obtained by the more laborious extraction methods employing ammonium acetate and calcium acetate as reagents. In most cases, the differences in the values obtained by the two extraction methods were somewhat greater than the differences between the values obtained by the quick method and the values found by the extraction procedures.

Puri and Uppal (10) reported that all extraction methods gave values that corresponded to certain fixed points on a neutralization curve and, therefore, could not be expected to give identical values.

It seems logical to suggest that the more rapid and less laborious quick method is reliable enough to be used along with other quick tests for diagnosing soil needs and for use in soil classification. In the study of the profiles of a large number of soil samples, the leaching methods could be advantageously replaced by this rapid method which would show the general trend of the base exchange capacity in the profile.

Some unpublished data, obtained in this laboratory, have shown that both air drying and oven drying of wet soils as collected in the field cause much greater variations in results obtained for the exchange capacities than the variations observed between the values obtained by the extraction methods and the quick method; therefore, the use of the quick method for determining the exchange capacities of soils under field conditions should give results that are more characteristic of the soils than those obtained with dried soils.

The ease of manipulation of the quick method for the base exchange capacity of soils and the small amount of equipment needed for its determination should make the method applicable for testing of soils in the field. The adaptation of this method to the testing of soils in the field is being studied with the hope that it may be valuable in determining lime and fertilizer needs under various field conditions. Specifically, further study is being conducted to determine the influence of base exchange capacity on the availability of potassium in soils and the lime requirement of soils.

SUMMARY

A rapid colorimetric method for determining the base exchange capacity of soils based on the sorption of copper from a standard cupric acetate-acetic acid solution by a definite quantity of soil is presented. The exchange capacity is found by measuring the decrease in copper concentration produced in a measured volume of the cupric acetate-acetic acid reagent by a weighed quantity of soil. The acidity of the reagent is adjusted to 0.07 normal with respect to acetic acid and to 0.2 normal in cupric ions for best results. The soil is shaken with the reagent to insure a practically complete reaction and the resulting suspension is filtered. The quantity of copper remaining in a measured volume of the filtrate is determined colorimetrically by treating the filtrate with dilute ammonium hydroxide to produce the stable, highly colored cupra-ammonio complex ion and then comparing the intensity of the color produced with standards containing known quantities of copper. The values obtained by this quick method with 21 soils correlated reasonably well with those obtained by two different leaching methods and took only a fraction of the time required by the leaching methods. Visual comparison of the unknown solutions with the standards was made in a simple and convenient combination filter rack and color comparator.

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RETENTION BY SOILS OF THE SULFUR OF VARIOUS COMPOUNDS AS REVEALED BY SUBSEQUENT PLANT GROWTH[1]

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An increasing number of sulfur-deficient areas have been recognized in the West during the last few decades. As virgin lands have been farmed until yields have declined, the order of nutrient deficiencies to appear has been, on the average, considered to be first nitrogen, second phosphorus, and third potassium. Evidence from crop responses to various nutrients applied indicate that for areas of some size in the West and for the crops grown the order of nutrient deficiencies which appear is first nitrogen and second sulfur. For the economic growth of legumes on these areas, assuming adequate inoculation and efficient nitrogen fixation, sulfur is the first element to become deficient. In consequence, a study of the plant nutrient economy of these areas requires that the sulfur relationships of these soils be given due consideration.

The factor of percolating waters from rainfall or irrigation enters into the ultimate application of many soil-fertility findings to field conditions. As with phosphorus (4)[3] and nitrogen (5), attention should be given to the reactions of sulfur compounds with the soil and especially the retention of applied water-soluble sulfur compounds by the soil. Sulfates are known to move with the percolating waters through the soil and to be retained by the soil solids only weakly, if at all. Less is known, however, of the behavior of other important sulfur compounds, including those dissolved in rain or irrigation water and those which occur as intermediate or final products of inorganic as well as organic transformations in the soil. Some other sulfur-containing compounds were also included in this study.

METHODS

The procedure described by Conrad and Adams (6) was employed, since by its use not only was the effect of the compound in question, or its decomposition products, on the growth of the test plants disclosed, but in general the type of reaction of the compound with the soil was also revealed. Each of several 4-inch red clay pots previously coated with asphaltum paint was prepared for these experiments by placing a square of waxed paper over the drainage hole to hold the soil and then by adding to the pot 400 grams of dry soil deficient in sulfur. Three pots so prepared were stacked to make a column and three or more columns were provided for each sulfur-containing aqueous solution to be tested. Sufficient solution to wet in slight excess, the total amount of dry soil in the column was added in installments to the top pot of the column in question. Additional columns were similarly percolated with distilled water for checks. After standing for a few hours, the columns were taken down and cropped to milo. As stated specifically later all

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication August 31, 1940.
[2]Associate Professor of Agronomy.
[3]Figures in parenthesis refer to "Literature Cited", p. 45.

pots in a given experiment were planted either before percolation or all at some time afterwards. Each pot was nested into its drainage can, the drainage water being returned to the pot several times during the growth period. As nitrogen was also a deficient element, some form of this nutrient was added equally to each pot in a given experiment as stated in detail later.

The final distribution of the sulfur was judged by the increased growth over that of the corresponding pots of the distilled water columns or in the case of toxic sulfur compounds, the reduced growth. Nearly equally enhanced or reduced growth in a given column indicated that the sulfur-containing units were only weakly, if at all, retained by the solid phase of the soil. Increases in growth in the top pots with smaller or no increases in the lower pots, or corresponding decreases in the case of toxic compounds, indicated a retention of sulfur-containing units by the soil.

All soils used were known to be moderately to strongly deficient in sulfur under greenhouse culture conditions. Nacimiento clay loam C-46, Linne clay loam C-48, and Huerhuero sandy loam C-50 were from fields dry-farmed biennially to small grains, the lots being collected soon after the grain harvest. These soils are described in the report of the Paso Robles area (2). The Vina loam C-33 was from a prune orchard, about 6 miles southeast of Red Bluff. Bur clover as a cover crop in an adjoining part of the orchard responded markedly to applications of gypsum. Other carriers of sulfur have given similar responses to legumes in this area. This soil is described in the soil survey of the Red Bluff area (8).

The sulfur compounds used are indicated below. The chemical formula as given was used in calculating the sulfur content of each compound. Those of the first group were "C.P." grade: Sodium pyrosulfite, $Na_2S_2O_5$; sodium thiosulfate, $Na_2S_2O_3 \cdot 5H_2O$; sodium sulfate, $Na_2SO_4 \cdot 10H_2O$; sodium sulfite, Na_2SO_3; sodium sulfide, $Na_2S \cdot 9H_2O$; sodium thiocyanate, NaCNS; carbon disulfide, CS_2; and sulfanilic acid, $NH_2C_6H_4SO_3H$.

The following were Eastman Kodak Company's highest purity chemicals: Ethyl sulfite, $(C_2H_5)_2SO_3$; potassium ethyl sulfate, $KC_2H_5SO_4$; ethanethiol, C_2H_5SH; ethyl disulfide, $(C_2H_5)_2S_2$; thio-acetic acid, CH_3COSH; potassium ethane sulfonate, $KOSO_2C_2H_5$; potassium ethyl xanthate, $KS_2COC_2H_5$; thiourea, $(NH_2)_2CS$; cysteine hydrochloride, $HSCH_2CHNH_2COOH \cdot HCl$; *l*-cystine, $(SCH_2CHNH_2COOH)_2$; and taurine, $HO_3S\ CH_2CH_2NH_2$. The other substances used were of lower grades.

EXPERIMENTS

In the experiments referred to in Table 1, the percolating nutrient solutions were each prepared so as to furnish about 1.5 milligram atoms of sulfur for each column. Triplicate columns were used. The seed was planted in the dry soil before percolation. At the same time, a "control" was established for each test solution consisting of triplicate pots not in a column. Each of these pots received a volume of solution equal to one-third that percolated through each column. After the columns were taken down, two crops of milo were grown in succession, the first from March 22 to April 28, 1938, and the second from May 6 to June 1. Additional nitrogen was supplied by adding 8 milligram atoms of nitrogen in the form of urea to each pot for the first crop and 5 for the second.

The tap water available for irrigation contained considerable amounts of sulfates. In consequence, distilled water was used for

TABLE 1.—*Retention of the sulfur from various percolating solutions by a sulfur-deficient soil, Huerhuero sandy loam, in columns of 4-inch pots as expressed by subsequent plant growth.*

Percolating solution	Average yield of green milo, grams per pot							
	First crop				Second crop			
	Top pot	Middle pot	Bottom pot	Control	Top pot	Middle pot	Bottom pot	Control
Inorganic substances:								
Distilled water, H_2O	2.4	1.9	4.1	5.2	1.5	1.0	1.2	1.4
Sodium persulfate, $Na_2S_2O_8$	18.5*	16.1*	15.8†	20.3*	4.0	3.0	3.9	7.3*
Sodium sulfate, $Na_2SO_4 \cdot 10H_2O$	23.4*	20.0*	20.8*	27.3*	8.1*	7.5*	4.3	8.7*
Sodium thiosulfate, $Na_2S_2O_3 \cdot 5H_2O$	24.0*	23.4*	25.2*	28.2*	7.2*	8.6*	8.6*	9.3*
Sodium sulfite, Na_2SO_3	24.8*	23.6*	22.6*	26.7*	3.9	6.6†	8.6*	6.3
Sodium pyrosulfite, $Na_2S_2O_5$	24.9*	23.2*	23.3*	27.6*	8.2*	7.9*	7.6*	9.7*
Sodium hydrosulfite	28.8*	27.4*	26.6*	27.7*	8.1*	8.3*	7.4*	8.0*
Sodium sulfide, $Na_2S \cdot 9H_2O$	18.0*	21.2*	20.4*	26.0*	6.2	6.5*‡	2.6†	9.1*
Miscellaneous organic substances:								
Potassium ethyl sulfate	25.3*	22.5*	22.5*	26.5*	7.5*	6.3†	6.8*	9.4*
Ethyl sulfite, $(C_2H_5)_2SO_3$	4.1	4.0	6.3	6.9†	1.0	0.9	1.2	1.4
Egg albumin	20.0*	23.2*	15.5*	25.4*	4.6†	5.3†	2.0	4.6*
Blood albumin	23.7*	25.7*‡	9.2*	31.0*	7.6*§	3.2*	1.3	4.0
Methylene blue, $C_6H_{18}N_3SCl$	1.5	1.8	3.2	4.0	1.6	1.1	1.4	1.5
Derivatives of hydrogen sulfide:								
Ethanethiol, C_2H_5SH	12.8*§	9.6*	8.1†	14.0*	1.9	1.8	1.5	1.8
Ethyl disulfide, $(C_2H_5)_2S_2$	14.5*‡	6.5*	5.4†	12.9*	1.7	1.5	1.4	1.3
Thio-acetic acid, CH_3COSH	25.4*§	20.7*	15.6†	26.4*	4.0	3.4*§	1.7	3.7*
Potassium ethane sulfonate, $C_2H_5SO_2OK$	26.6*	25.3*	23.8*	25.0*	7.8*	8.4*	6.6†	9.2*
Carbon disulfide and derivatives:								
Carbon disulfide, CS_2	3.6	3.0	5.7	7.0†	1.0	1.1	1.4	1.7
Potassium ethyl xanthate, $KS_2COC_2H_5$	1.3§	19.5*§	7.9†	7.3	5.4*	3.9†	2.0	2.5
Sodium thiocyanate, NaSCN	0.0*	0.0†	0.0*	0.0*	7.3†	3.9	7.4†	0.7
Thiourea, $(NH_2)_2CS$	1.5	0.7	0.9†	0.0*	2.1	2.2	2.8*	2.5

Statistically different (7, p. 114) from the corresponding pots of the distilled water columns:
*P = 0.01 or less. †P lies between 0.01 and 0.05.
Statistically different (7, p. 112) from the value in the column to the right and for the pot next below it in the column of pots:
‡P = 0.01 or less. §P lies between 0.01 and 0.05.

irrigation throughout all of these experiments, except for the following two treatments, each in triplicate cultures. In one treatment, all watering was with tap water, the yield averaging 24.4 grams per pot. In the other, each pot received 100 ml of tap water to start growth and distilled water thereafter, the yield averaging 12.1 grams per pot. These values are directly comparable with those for the "control" of the distilled water treatment for the first crop (cf. Table 1), namely, 5.2 grams per pot.

No retention of the sulfur of the inorganic sources tested was in evidence in the first crop. In the second crop, however, the yields of the middle pots in the columns subjected to percolation with sodium sulfide indicated that some sulfur-containing unit had been at least partially retained by the soil.

With the water-soluble blood albumin, considerable retention was in evidence in both crops. With egg albumin, although the averages as given might indicate some retention, the variability of the triplicate cultures was so great that the differences were not significant. Using higher concentrations and a different soil, retention of the nitrogen of egg albumin was demonstrated in another experiment carried out in such a way as to show the retention of nitrogen (5). The sulfur of methylene blue was not made available to the test plants in this experiment even by the time of the second crop. Visual evidence at the time of percolation, however, indicated that the methylene blue was all retained in the top pot, since the surface of the soil was very blue, while the surface of the second and third pots as well as the percolates showed no blue coloration. The sulfur of ethyl sulfite gave a significant but small increase only in the control of the first crop.

Fig. 1 is a photograph of the first crop of several of the cultures reported in Table 1, showing some of the different types of response obtained.

Conant (3) divides the organic sulfur compounds into derivatives of H_2S and of CS_2. Of the four derivatives of H_2S tested, three, ethanethiol, ethyl disulfide, and thio-acetic acid, gave definite evidence of retention of some of the sulfur by the soil as indicated by the yields of the first crop. The second crop also indicated retention in the case of thio-acetic acid.

Among CS_2 and its derivatives, only one compound showed availability of much of its sulfur to the plants, while sodium thio-cyanate was definitely toxic throughout the soil column to the first crop. By the time of the second crop, at least some of this sulfur had become available, while the toxicity either disappeared or was materially lessened. If higher amounts of potassium ethyl xanthate be considered toxic, while lower amounts furnish available sulfur to the plants, the yield data for the first crop may be considered to indicate a retention of a considerable amount of this sulfur compound by the top pot with progressively less with increasing depth in the column.

Because of the evidence of sulfur-retention with Na_2S and other derivatives of H_2S, it seemed desirable to make tests with the other sulfur-deficient soils. Consequently, the experiments reported in

Table 2 were carried out. The pots with the Huerhuero sandy loam were percolated on August 26, planted September 15, and harvested November 2, 1938. The solutions were prepared so as to supply 0.2 milligram atoms of sulfur per colum. After percolation 12.4 milligram atoms of nitrogen as nitrate were added to each pot. The other soils were planted before wetting, percolated on November 4, and har-

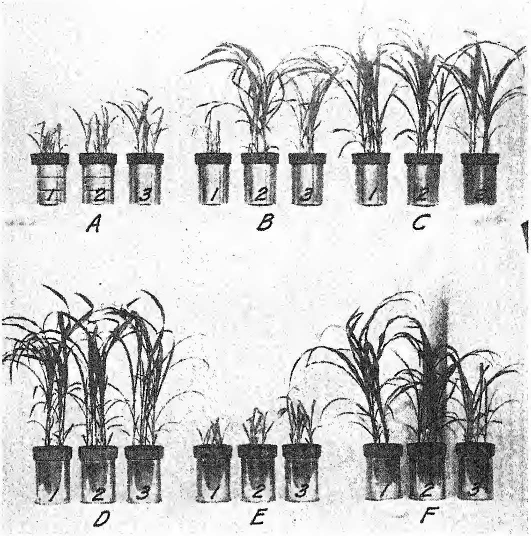

FIG. 1.—First crop of milo in retention-of-sulfur experiments with Huerhuero sandy loam. The numbers 1, 2, and 3 indicate the order of the pots in each percolating column beginning at the top. Percolating solutions were as follows: A, distilled water; B, potassium ethyl xanthate; C, egg albumin; D, potassium ethyl sulfate; E, methylene blue, and F, thio-acetic acid.

vested December 30, 1938. Uric acid as a source of nitrogen was mixed at the rate of 0.4 gram with each 400-gram lot of the dry soil before placing the soil in the pot. All of these tests were conducted in triplicate. Though there was significant response to the applications of sulfur with all of the soils, only with the Huerhuero sandy loam was there any significant evidence of the retention of the sulfur of Na_2S.

The results reported in Table 3 are from tests with additional com-

TABLE 2.—*Retention of the sulfur of sodium sulfide by some sulfur-deficient soils as shown by the subsequent response of milo.*

Soil type	Average yield of green milo, grams per pot, in columns percolated with					
	Distilled water			Sodium sulfide		
	Top pot	Middle pot	Bottom pot	Top pot	Middle pot	Bottom pot
Huerhuero sandy loam	3.0	2.7	2.8	8.8†‡	4.7*	5.2*
Vina loamy..........	3.0	5.2	6.8	10.4*	9.4†	9.8
Nacimiento clay loam.	3.7	4.1	4.7	9.7*	9.7*	11.9*
Linne clay loam......	4.5	5.1	4.8	7.8†	7.1	7.8†

Statistically different (7, p. 114) from the corresponding pots of the distilled water columns: *P = 0.01 or less. †P lies between 0.01 and 0.05.
‡Statistically different (P lies between 0.01 and 0.05) from the value to the right and for the pot next below it in the column of pots.

pounds and soils. The pots containing the Huerhuero soil were percolated on September 22, planted October 3, and harvested December 15, 1938. The solutions being tested were prepared so as to supply 0.3 milligram atom of sulfur per column. Nitrates to the extent of 7.4 milligram atoms of nitrogen were added to each pot during the early part of the growing season. There was no significant evidence of retention of the sulfur of taurine and sodium taurocholate (compounds occurring in the bile), nor of calcium sulfocarbolate. The evidence of appreciable retention of the sulfur of cystine and cysteine was significant.

TABLE 3.—*Retention of the sulfur of various compounds by two sulfur-deficient soils as shown by the subsequent response of milo.*

Soil and percolating solution	Average yield of green milo, grams per pot		
	Top pot	Middle pot	Bottom pot
Huerhuero sandy loam:			
H_2O (distilled)........................	3.7	4.3	5.5
Cysteine hydrochloride................	19.6*§	9.5†§	5.0
Cystine............................	18.6*§	13.6*‡	7.6
Taurine............................	6.8	7.5†	7.9†
Sodium taurocholate..................	6.9†	7.3	8.2
Calcium sulfocarbolate................	5.9†	7.0†	7.6
Linne clay loam:			
H_2O (distilled)........................	2.5	2.5	2.8
CS_2..............................	4.0†	3.3	2.8
Thiourea $(NH_2)_2CS$....................	6.9*	8.5*	6.6*
Sulfanilic acid........................	3.3†	3.6*	3.6

Statistically different (7, p. 114) from the corresponding pots of the distilled water columns: *P = 0.01 or less. †P lies between 0.01 and 0.05.
Statistically different from the value to the right and for the pot next below in the column of pots. ‡P = 0.01 or less. §P lies between 0.01 and 0.05.

In the experiments with the Linne clay loam the columns were percolated on August 28 and in order to allow time for toxicity to be reduced planting was deferred until September 15. Solutions of carbon disulfide were calculated to supply 1.67 milligram atoms of sulfur per column, the others 0.4 milligram atom per column. The plants were harvested November 2, 1938. Nitrates to the extent of 12.4 milligram atoms of nitrogen were added to each pot. No further evidence with regard to retention was disclosed, but the availability, especially with the preplanting period of incubation, was increased or toxicity decreased with some of these compounds.

DISCUSSION

Among the inorganic sulfur compounds, such as persulfate, sulfate, thiosulfate, sulfite, pyrosulfite, hydrosulfite, and sulfide, no retention was evidenced in the first crop, and all these forms gave substantial and highly significant responses to the sulfur contained therein. Potassium ethyl sulfate gave no evidence of being retained by the soil. Evidently the replacement of one of the hydrogens of sulfuric acid by an ethyl group has had little, if any, effect on the retention of its sulfur by the soil. Tests, not reported herein but made simultaneously with those reported in Table 1 with a commercial soap, sodium alkyl sulfate, gave the same type of behavior as did potassium ethyl sulfate.

No evidence of retention of the sulfur from the above compounds occurred even with the second crop except from sodium sulfide. With this compound there was statistically significant retention. By reducing the amount of sulfur per column to about 13% of that in the former tests, as with tests reported in Table 2, statistically significant retention of the sulfur of Na_2S was demonstrated by the first crop grown on Huerhuero sandy loam. With the other three soils there was no clearcut evidence, although with the Vina loam there was a suggestion of retention. The increases in yield over cases involving percolation with distilled water were for the top pots 7.4 grams, while for the bottom pots they averaged only 3.0 grams. These differences were not statistically significant.

There was evidence of retention of the sulfur of three other derivatives of H_2S by Huerhuero sandy loam; ethanethiol (ethyl mercaptan), ethyl disulfide, and thio-acetic acid. The fourth organic derivative of H_2S, potassium ethane sulfonate, gave no significant evidence of retention.

Retention by the soil of sulfur from solutions containing Na_2S could be explained by the precipitation of the very difficultly soluble substances, FeS and elementary sulfur. Kappen and Quensell (9) presented evidence that both were quickly formed when H_2S came in contact with moist soil according to the following reaction: $3H_2S + Fe_2O_3 = 2FeS + 3H_2O + S$. They also postulated the rapid regeneration of the ferric oxide with the liberation of the sulfur in the elementary form. If soils differ materially in the rate at which these reactions go on, or in the amount or reactivity of the iron compounds present, the differences in behavior observed among the soils percolated with solutions of Na_2S might be explained.

The retention by the soil of the sulfur of thio-acetic acid may result from the splitting off of H_2S, which is said (1) to occur quite readily, and the resulting formation of FeS and sulfur in the soil. The reactions responsible for retention in the case of ethane-thiol and ethyl disulfide are somewhat more obscure. It is suggested that mechanisms may exist for the easy splitting of H_2S from their respective molecules.

The two sulfur-containing amino acids, cysteine and cystine showed significant retention of their sulfur by the Huerhuero sandy loam. This is the same type of behavior as was exhibited when cysteine was percolated as a source of nitrogen through columns of soils deficient in nitrogen. (5). In that study, the cysteine was about 20 times as concentrated as in the present study. It was suggested that cysteine might have been oxidized to the much less soluble cystine and precipitated out during percolation. The same transformation might have occurred in the present experiments, but the concentration of cystine possible would be less than that of a saturated solution. Furthermore, cystine itself gave much the same type of response. In fact this same type of behavior was obtained in the nitrogen study (5) with the amino acids, glycine and glutamic acid. The best explanation at present seems to be that these amino acids, with little or no decomposition, were adsorbed only weakly by the soil solids so that part of the nitrogen was retained by the soil of the respective top pots and part went through to the pots below.

Carbon disulfide did not significantly furnish available sulfur to the plants in the Huerhuero sandy loam and barely did with the Linne clay loam when approximately 18 days of incubation was allowed between percolation and planting. Perhaps much of the sulfur was lost by volatilization.

Sodium thiocyanate proved toxic throughout all of the cultures of the first crop, but by the time of the second crop the toxicity had largely disappeared. There was evidence also that the thiocyanate had changed to forms of sulfur less toxic but still available to the plant. Sandhoff and Skinner (10) have made a study of the decomposition of this herbicide in the soil, but submit no evidence with regard to its retention by the soil.

Thiourea gave some evidence of toxicity in the first crop grown on Huerhuero sandy loam (cf. Table I). This injury had disappeared by the time of the second crop, but there was little evidence of response from the sulfur applied. With the Linne clay loam (cf. Table 3) when 18 days of incubation occurred between percolation and planting, there was no evidence of toxicity, and a highly significant response to the sulfur occurred. In another study (5) designed to test the retention of nitrogen compounds, thiourea at a much higher concentration gave significant toxicity in all pots of the column with no significant evidence of any retention.

The data presented here give preliminary information regarding the value of various sulfur compounds as sources of sulfur for growth, and also evidence regarding the reactions of these compounds with the soil. Many questions are raised, however, especially with regard to

the mechanisms of retention of the sulfur of some of these compounds. Further work in this field is contemplated.

SUMMARY

In many important areas in the West sulfur is the first essential element to become deficient for the leguminous crops generally grown. A knowledge of the retention by soils of the sulfur of various compounds whether they be applied directly or whether they arise indirectly as intermediate or final products of sulfur metabolism is necessary for a complete understanding of the sulfur relationships of these soils. In this study of retention, a solution of each sulfur compound tested was percolated through a column of three pots containing soil deficient in sulfur. Check columns were percolated with distilled water. The volume of liquid used was sufficient without great excess to wet all of the soil in the column. After percolation each pot was cropped to milo, an equal amount of available nitrogen being added to each pot. In all pots of a column percolated with a solution of a sulfur compound equal growth increases over the corresponding pots of the distilled water columns (or in the case of toxicity, decreases) indicated non-retention. Greater increases, or decreases, in the top pots than in the lower ones indicated retention by the soil.

Significant retention of sulfur was thus demonstrated for sodium sulfide, ethanethiol, ethyl disulfide, thio-acetic acid, potassium ethyl xanthate, cysteine, cystine, and blood albumin.

Significant response, but with no significant evidence of retention, was secured with sodium persulfate, sodium sulfate, sodium thiosulfate, sodium sulfite, sodium pyrosulfite, potassium ethyl sulfate, potassium ethane sulfonate, taurine, sodium taurocholate, calcium sulfocarbolate, and egg albumin. With these compounds the yields of the pots in each column were nearly equal thereby giving no evidence of retention of these compounds.

Sodium thiocyanate gave significant evidence of immediate toxicity in all pots, and no evidence of retention. Subsequent decomposition resulted in a positive response in the second crop. Thiourea likewise showed some toxicity at first, but experiments allowing time for incubation before planting gave nearly equal significant increases from all pots of the column.

The rapid formation of the very difficultly soluble FeS and sulfur could explain the retention of the sulfur of Na_2S. Thio-acetic acid, ethanethiol, and ethyl disulfide may have split off H_2S with the subsequent formation of FeS and sulfur, thereby causing retention. The amino acids, cysteine and cystine, were probably retained by moderately weak but definite adsorption.

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A SUMMARY OF LINKAGE STUDIES IN BARLEY[1]

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PLANT breeders and geneticists have long felt the need of standardizing the system of genetic nomenclature and symbols for the various crops. In order to adhere to a uniform type of nomenclature and symbols, the method of assigning symbols used by the maize geneticists and summarized by Emerson, *et al.* (12)[3] have been used as a basis.

In general, characters are given a name suggestive of one of their chief attributes. The symbol consists of the initial letter of the name of the character or of the initial letter with some other appropriate letter in the name. Allelomorphic series of genes have a common basic symbol and are differentiated by superscript letters. Phenotypically similar characters are usually given the same name and differentiated by subscript numerals or letters.

In order to standardize the use of names and symbols, it would appear that, prior to publication, the name and symbol intended for use conform with the general principles given above and the list given in the following pages.

GENETIC FACTORS

In Table 1 is presented a list of characters studied by the various workers in barley genetics. Recommended symbols are given for each character, as well as the previous symbols used when different from the recommended symbol and the author describing the character. The symbols are listed alphabetically to facilitate the allotting of new symbols to additional characters.

In making this list, direct reference is given to authors who gave symbols to the characters or studied the linkage relationship of several factor pairs. Some of the earlier workers who reported simple mendelian ratios for certain factor pairs are, therefore, omitted.

LINKAGE GROUPS

The linked genes are placed in seven linkage groups corresponding to the seven chromosomes. Linkage groups have been established on the independent inheritance of genes in different chromosomes. The linkages and associations reported in the literature are listed in Table 2.

[1]Contribution from the Department of Agronomy, Colorado Agricultural Experiment Station, Fort Collins, Colo., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St. Paul, Minn., cooperating. Received for publication October 21, 1940.

[2]Agronomist, Colorado Agricultural Experiment Station; Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture; and Plant Geneticist, Minnesota Agricultural Experiment Station, respectively. Published with the approval of the Directors as Journal Series paper 109 of the Colorado Agricultural Experiment Station and Journal Series paper 1843 of the Minnesota Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 62.

TABLE 1.—*Genetic factors studied by workers in barley genetics.*

Character	Recommended symbol	Previous symbol used	Authority*
Normal vs. albino seedlings	Aa		8
Normal vs. albino seedlings	A_1a_1		36, 18
Normal vs. albino seedlings	A_2a_2		36, 18
Normal vs. albino seedlings	A_3a_3		36, 18
Normal vs. albino seedlings	A_4a_4		18
Normal vs. albino seedlings	A_ca_c	Aa	40, 30
Normal vs. albino seedlings	$A_{c2}a_{c2}$		41, 47
Normal vs. albino seedlings	$A_{c3}a_{c3}$		45
Normal vs. albino seedlings	A_ba_b		43
Normal vs. albino seedlings	A_na_n		47
Normal vs. albino seedlings	A_ta_t		40
Normal vs. albino seedlings	$A_{t2}a_{t2}$		43
Normal vs. albino seedlings	$A_{t3}a_{t3}$	Alb^talb^t	11, 7
Normal vs. albino seedlings	A_ha_h		43
Black vs. white lemma and pericarp	Bb	Bk bk	21, 22, 30, 40, 8, 39, 7, 23
Blue vs. non-blue aleurone	Bl bl		7, 42
Normal vs. brachytic	Br br		39, 51, 6
Complementary factors for brittle rachis	Bt bt Bt_1bt_1		61
Straight vs. curved peduncle	Cr cr		7
Tall vs. sterile dwarf	Dd		32
Awnless vs. awned outer glumes	Ee		22, 2
Early vs. late (several factors)	Ea ea	Ee, Xx, Yy, Zz	17, 35
Complementary factors for folsum vs. vernum base on grain	Er_1er_1		56
	Er_2er_2		56
Green vs. chlorina	Ff		36, 18, 42, 6
Green vs. chlorina	F_cf_c		41
Green vs. chlorina	$F_{c2}f_{c2}$		46
Toothed vs. untoothed lemma	Gg		67
Normal vs. glossy	Gl gl Gl_2gl_2		Unpublished
Growth factors	Gr gr		45
Tall vs. short	Hh	Uu	55, 31, 35
Resistance vs. susceptibility to H. sativa (3 factors)	Hl hl		17
Fertile intermedium vs. non-intermedium	I^hi	Bb	19, 29
Infertile intermedium vs. non-intermedium	Ii	Ww	40, 60, 15, 7, 35
3rd factor for fertility of the lateral floret	I_1i_1	Dd	15
Complementary factor inhibiting red pericarp color	Jj		7
Complementary factor inhibiting red pericarp color	J_1j_1	Ii	7
Hooded vs. awned	Kk	Aa, C_1c_1	61, 22, 30, 40, 21, 7, 9, 8, 23, 16, 31
Hooded vs. long awned	Kl kl	Aa, Vv, A_1a_1	61, 63, 31†
Hooded vs. long awned	Kl_1kl_1	A_2a_2	31
Dense vs. lax (long vs. short internode)	Ll		62, 35
Dense vs. lax	L_1l_1		31, 66†
Dense vs. lax	L_2l_2		31, 66†

*Figures refer to "Literature Cited", p. 62.
†May not be the same factor.

TABLE I.—*Continued.*

Character	Recommended symbol	Previous symbol used	Authority*
Dense vs. lax	L_3l_3		67
Dense vs. lax	L_4l_4		67
Dense vs. lax	L_5l_5		67
Dense vs. lax	L_al_a		65
Long vs. short outer glume	Log log	Ll	34
Complementary factors giving a lethal progeny	Lp_1lp_1 Lp_2lp_2		68
Normal vs. reduced lateral spikelet appendage on the lemma	Lr lr	Ii, Nn	31, 16, 29
Awned vs. awnless	Lk lk	Ss	14, 28
Awned vs. dehiscent awn	Lk_ulk_u		54
Series of factors for awn length	$Lk_{1,2,3}lk_{1,2,3}$	Aa, Bb, Ii	13
Hulled vs. naked	Nn	Hh, Ss	22, 40, 7, 8, 23, 31, 34, 55, 21
Normal vs. many noded dwarf	Mm		20, 22
Resistance vs. susceptibility to mildew (form 3)	Ml_aml_a		5
Resistance vs. susceptibility to mildew (form 3)	Ml_hml_h	Hh	4
Resistance vs. susceptibility to mildew (form 3)	Ml_gml_g	Gg	4
Resistance vs. susceptibility to mildew (form 3)	Ml_kml_k		5
Normal vs. male sterile	Ms ms		50
Unbranched and branched ear (duplicate factors)	Nb nb, Nb_1nb_1	N_1n_1, N_2n_2	1
White vs. orange lemma	Oo	Br br, Pl pl, Gg	7, 23, 31, 52†
Green vs. orange seedlings	Or or		48
Purple vs. white lemma	Pp		7, 8
Purple vs. white lemma	P_1p_1		31
Purple vs. white lemma	P_2p_2		31
Purple vs. white veined lemma (1 factor)	P_cp_c	Cc	7
Purple vs. white veined lemma (1 factor)	P_ep_e	Ee	7
Purple vs. white veined lemma (1 factor)	P_fp_f	Ff	7
General vs. restricted pubescence of outer glume	Pbg pbg	Ss	22
Purple vs. white straw	Pr pr		44
Rough vs. smooth awn	Rr	Aa	22, 17, 30, 49, 8, 42, 67, 9
Intermediate rough vs. smooth awn	R_1r_1	R^1r^1 Ss, Ii	9, 42, 17, 49
Dominant factor for smooth awn	R_2r_2	Aa	9
Rough vs. smooth awn	R_3r_3		64
Red vs. white pericarp	Re re	Oo	7
	Re_1re_1	Rr	7
Rachis internode number	Rin rin	Ss	52
Long vs. short-haired rachilla	Ss	Ll	30, 40, 8, 22, 49, 7, 67, 23
Resistance vs. susceptibility to *P. graminis tritici*	Tt		38
Normal vs. "third outer glume"	Trd trd	Tt	23

*Figures refer to "Literature Cited", p. 62.
†May not be the same factor.

TABLE 1.—*Concluded.*

Character	Recommended symbol	Previous symbol used	Authority*
Branched vs. unbranched style (3 factors)	Uu, U_1u_1, U_2u_2	$Gg, G'g', G''g''$	41, 42
Non-six row vs. six-row	Vv	Aa, Zz, a^s, a^t, a^f	17, 40, 8, 19, 35, 60, 15, 55, 22, 23, 21
Deficiens vs. sub-deficiens	V^t	Tt	55
Narrow vs. wide glumes	Ww	Ii	22, 23
Presence vs. absence of waxy bloom on stem and head	Wh_1wh_1	Ww	23
Absence vs. presence of waxy bloom on head	Wh wh		23
Inhibiter of wide glumes	Wi wi	Ii	22
Presence vs. absence of waxy bloom on leaves	Wl wl		58
Normal vs. yellow seedlings (Xantha)	Xx	Dd	36
Normal vs. xantha seedlings	X_cx_c		40
Normal vs. xantha seedlings	X_sx_s		47
Normal vs. xantha seedlings	$X_{c2}x_{c2}$		41
Normal vs. xantha seedlings	X_nx_n		44
Normal vs. virescent seedlings	Yy		36, 18, 48,
Normal vs. virescent seedlings	Y_cy_c		41

*Figures refer to "Literature Cited", p. 62.

TABLE 2.—*Linkages and associations reported in studies of barley genetics.*

Linkages	Recommended symbol	Previous symbols used	Percentage recombination	Authority*
Group I				
Non-six-rowed vs. six-rowed (Vv) in relation to:				
1. Toothed vs. untoothed lemma	Gg		16.6	67
2. Toothed vs. untoothed lemma	Gg		15.4	67
3. Purple vs. colorless grain......	Pp	Pl pl		8, 31
4. Awnless vs. awned............	Lk lk	Ss		14
5. Normal vs. reduced lateral spikelet appendage on the lemma....................	Lr lr	Ii		31, 29
6. Awnless vs. awned............	Lk lk		9.6	28
7. Tall vs. short................	Hh	Uu		31
8. Long vs. short awned.........	Lk_1lk_1	A_2a_2		31
9. Extended vs. narrow outer glumes..................	Ww		40.5	22
10. Early vs. late heading.........	Ea ea	Ee	42.0	17
11. Early vs. late heading.........			Correlated	67
12. Resistance vs. susceptibility to *H. sativum*...............	Hl hl		Correlated	17
13. Tall vs. short................	Hh		Correlated	55
14. Tall vs. short................	Hh		Correlated	35
15. Dense vs. lax................	Ll		Correlated	35
16. Long vs. short internode.......	L_4l_4		40.0	67
17. Early vs. late (1 factor).......	Ea ea		Correlated	35
18. Long vs. short outer glumes....	Log log	Ll	Correlated	35
19. Purple vs. white-veined lemma.	P_cp_c	Cc	22.2	7
20. Red vs. white pericarp........	Re_1re_1	Rr	18.6	7
21. Purple vs. white lemma.......	Pp	Pp	19.4	7
22. Green vs. chlorina seedlings....	Ff		18.3	42
23. Purple vs. white straw........	Pr pr		9.0	44
24. Brown-yellow vs. white lemma (possibly orange lemma)....		Gg	38.6	52
25. Green vs. white seedlings......	Aa		26.9	8
26. No awns vs. awns on outer glumes..................	Ee		24.7	2
27. Rachis internode number.....	Rin rin		32.9	53
28. Green vs. virescent seedlings...	Yy		31.3	48
29. Green vs. orange seedlings.....	Or or		31.2	48
30. Awned vs. dehiscent awn......	Lk_ulk_u		16.3	54
Purple vs. white-veined lemma (P_cp_c) in relation to:		Cc		
1. Red vs. white pericarp........	Re_1re_1	Rr	33.7	7
2. Purple vs. white lemma.......	Pp		34.3	7
Red vs. white pericarp (Re_1re_1) in relation to:		Rr		
1. Purple vs. white lemma.......	Pp		0.5	7
Early vs. late (Ea ea) in relation to:		Ee		
1. Resistance vs. susceptibility to *H. sativum*...............	Hl hl		Correlated	17

*Figures refer to "Literature Cited", p. 62.

TABLE 2.—*Continued.*

Linkages	Recommended symbol	Previous symbols used	Percentage recombination	Authority*
Group I—*Concluded*				
Green vs. chlorina seedlings (Ff) in relation to:				
1. Normal vs. albino seedlings....	A_3a_3		5.0	36
			10.2	18
2. Normal vs. albino seedlings....	A_4a_4		3.8	18
3. Green vs. virescent seedlings...	Yy		0.8	48
4. Green vs. orange seedlings.....	Or or		8.7	48
Normal vs. albino seedlings (A_3a_3) in relation to:				
1. Normal vs. albino seedlings....	A_4a_4		12.5	18
Normal vs. virescent seedlings (Yy) in relation to:				
1. Green vs. orange seedlings.....	Or or		13.4	48
Normal vs. orange seedlings (Or or) in relation to:				
1. Normal vs. reduced lateral spikelet appendages of the lemma..................	Lr lr	Ii, Nn	27.8	29
Group II				
Black vs. white lemma and pericarp (Bb) in relation to:				
1. Normal vs. albino seedlings....	A_ta_t		22.3	40
2. Resistance vs. susceptibility to *H. sativum* (1 factor)........	Hl hl		Correlated	17
3. Normal vs. "third outer glume"	Trd trd	Tt	15.4–16.9	23
Group III				
Hulled vs. naked (Nn) in relation to:				
1. Hooded vs. long awned........	Kl kl	Aa	14.3	62
2. Dense vs. lax................	Ll		16.7	62
3. Dense vs. lax................	L_1l_1		13.0	31
4. Dense vs. lax................	L_al_a		40.0	65
5. Dense vs. lax (different cross)..	L_2l_2		23.0	31
6. Long vs. short awned.........	Lk lk	A_1a_1		31
7. Hooded vs. awned............	Kk	C_1c_1		31
8. General vs. restricted pubescence on outer glume.......	Pbg pbg	Ss	23–27	22
9. Green vs. albino seedlings.....	$A_{c2}a_{c2}$		27.2	47
10. Rough vs. smooth awn........	R_3r_3			64
Group IV				
Hooded vs. awned (Kk) in relation to:				
1. Dense vs. lax................	Ll		16–20	62
2. Blue vs. white aleurone........	Bl bl		40.6	7
			22.0	42
3. Infertile intermedium vs. non-intermedium.............	Ii		15.1	44
4. Fertile intermedium vs. non-intermedium.............	I^hi		13.1	29

*Figures refer to "Literature Cited", p. 62.

TABLE 2.—*Continued.*

Linkages	Recommended symbol	Previous symbols used	Percentage recombination	Authority*
Group V				
Rough vs. smooth awns (Rr) in relation to:				
1. Long vs. short-haired rachilla..	Ss	Ll	About 35	22
2. Long vs. short-haired rachilla..	Ss		42.7	30
3. Long vs. short-haired rachilla..	Ss	Ll	30.8	49
4. Long vs. short-haired rachilla..	Ss		34.6	42
5. Long vs. short-haired rachilla..	Ss		28.1	8
6. Long vs. short-haired rachilla..	Ss	Ll	30.0	67
7. Resistance vs. susceptibility to *H. sativum*................	Hl hl		Correlated	17
8. Long vs. short internode.......	L_2l_2		10.0	66
9. Early vs. late heading.........	Ea ea		Correlated	67
Long vs. short-haired rachilla (Ss) in relation to:				
1. Red vs. white pericarp........	Re re	Oo	34.7	7
2. White vs. orange lemma.......	Oo	Br br	39.1	7
3. Green vs. white seedlings......	A_ba_b		26.0	44
Group VI				
Green vs. xantha seedlings (X_cx_c) in relation to:				
1. Green vs. albino seedlings.....	A_ca_c		7–11	40
2. Growth factors affecting yield of grain..................	Gr gr			45
3. Green vs. albino seedlings.....	A_na_n		9.4	47
Green vs. albino seedlings (A_ca_c) in relation to:				
1. Green vs. xantha seedlings.....	X_sx_s		25.7	47
Green vs. albino seedlings (A_na_n) in relation to:				
1. Green vs. xantha seedlings.....	X_sx_s		15.5	47
Group VII				
Green vs. chlorina seedlings (F_cf_c) in relation to:				
1. Green vs. virescent seedlings...	Y_cy_c		29.3	42
2. Normal vs. brachytic.........	Br br		9.3	51
3. Normal vs. brachytic.........	Br br		9.8	6
4. Resistance vs. susceptibility to *P. graminis tritici*..........	Tt		16.7	6
Normal vs. brachytic (Br br) in relation to:				
1. Resistance vs. susceptibility to *P. graminis tritici*..........	Tt		12.6	6

*Figures refer to "Literature Cited", p. 62.

TABLE 2.—*Concluded.*

Linkages	Recommended symbol	Previous symbols used	Percentage recombination	Authority*
Miscellaneous				
Tall vs. short in relation to:				
1. Early vs. late	Ea ea		Correlated	35
2. Long vs. short outer glume	Log log	Ll	Correlated	35
Early vs. late in relation to:				
1. Long vs. short outer glume	Log log	Ll	Correlated	35
Dense vs. lax in relation to:				
1. Long vs. short outer glume	Log log	Ll	Correlated	35
Purple vs. white pericarp (Pp) in relation to:				
1. Green vs. white seedlings	Aa		17.9	8
Resistance vs. susceptibility to mildew (form 3) ($Ml_a ml_a$) in relation to:				
1. Resistance vs. susceptibility to mildew (form 3)	$Ml_k ml_k$		9.81	5

*Figures refer to "Literature Cited" p. 62.

TABLE 3.—*Factor pairs showing independent inheritance as reported by workers on barley genetics.*

Linkages	Recommended symbol	Previous symbol used	Authority*
Non-six-rowed vs. six-rowed (Vv) independent of:			
1. Long vs. short-haired rachilla	Ss	Ll	22, 30, 7, 67, 5
2. Hulled vs. naked caryopsis	Nn	Ss	22, 55, 40, 7, 35, 8, 21
3. General vs. restricted pubescence on the outer glumes	Pbg pbg	Ss	22
4. Hooded vs. awned	Kk		22, 40, 30, 21, 7, 8
5. Black vs. white glume color	Bb	Bk bk	21, 22, 17, 40, 30, 7, 8, 39
6. Normal vs. many noded dwarf	Mm		22
7. Rough vs. smooth awn	Rr		30, 8, 67, 17
8. Intermediate smooth vs. smooth	R_1r_1	Ss	17
9. Green vs. albino seedlings	A_ca_c	Aa	40, 30
10. Green vs. albino seedlings	$A_{t3}a_{t3}$	$Alb^t alb^t$	7
11. Purple vs. white-veined lemma	P_ep_e	Ee	7
12. Purple vs. white-veined lemma	P_fp_f	Ff	7
13. Straight vs. curved peduncle	Cr cr		7
14. Blue vs. white aleurone	Bl bl		7
15. Long vs. short internode	L_3l_3		67
16. Long vs. short internode	L_5l_5		67
17. Long vs. short internode	L_al_a		65
18. Resistance vs. susceptibility to mildew (*Erysiphi graminis hordei*) (form 3)	Ml_hml_h	Hh	3
19. Resistance vs. susceptibility to mildew (*Erysiphi graminis hordei*) (form 3)	Ml_gml_g	Gg	4
20. Resistance vs. susceptibility to mildew (*Erysiphi graminis hordei*) (form 3)	Ml ml		57
21. Green vs. albino seedlings	$A_{c2}a_{c2}$		47
22. Green vs. albino seedlings	A_na_n		47
23. Green vs. xantha seedlings	X_sx_s		47
24. Normal vs. brachytic	Br br		39
25. Presence vs. absence of waxy bloom on the leaves	Wl wl		58
26. Unbranched vs. branched ear (duplicate factor)	Nb nb, Nb_1nb_1	N_1n_1, N_2n_2	1
27. Normal vs. "third outer glume"	Trd trd	Tt	23
28. Fertile intermedium vs. nonintermedium	I^hi		29, 19
29. Nonfertile intermedium vs. nonintermedium	Ii		40
Red vs. white pericarp (Re_1re_1) independent of:			
1. Red vs. white pericarp	Re re	Oo	7

*Figures refer to "Literature Cited", p. 62.

TABLE 3.—*Continued.*

Linkages	Recommended symbol	Previous symbol used	Authority*
2. Straight vs. curved peduncle	Cr cr		7
3. Hulled vs. naked caryopsis	Nn		7
4. Blue vs. white aleurone....	Bl bl		7
Purple vs. white lemma (Pp) independent of:			
1. Long vs. short-haired rachilla................	Ss	Ll	7
2. Purple vs. white-veined lemma................	P_ep_e	Ee	7
3. Straight vs. curved peduncle	Cr cr		7
4. Blue vs. white aleurone....	Bl bl		7
5. Hulled vs. naked caryopsis.	Nn		7
Purple vs. white-veined lemma (P_ep_e) independent of:			
1. Purple vs. white-veined lemma................	P_ep_e	Ee	7
2. Straight vs. curved peduncle	Cr cr		7
3. Blue vs. white aleurone....	Bl bl		7
4. Green vs. albino (also independent of (P_ep_e and P_fp_f)................	$A_{t_3}a_{t_3}$	$Alb^{t}alb^{t}$	7
Green vs. chlorina seedlings (Ff) independent of:			
1. Green vs. albino seedlings..	A_ta_t		42
2. Green vs. albino seedlings..	A_ca_c		42
3. Green vs. chlorina seedlings	F_cf_c		42
4. Long vs. short-haired rachilla................	Ss		42
5. Hoods vs. awns...........	Kk		42
6. Green vs. albino seedlings..	$A_{c2}a_{c2}$		47
7. Green vs. albino seedlings..	A_na_n		47
8. Green vs. xantha seedlings	X_sx_s		47
9. Fertile intermedium vs. non-intermedium.......	I^bi		29
Normal vs. "third outer glume" (Trd trd) independent of:			
1. Hooded vs. awned........	Kk		23
2. Narrow vs. wide outer glume	Ww	Ii	23
3. Hulled vs. naked..........	Nn		23
4. Long vs. short-haired rachilla................	Ss		23
5. White vs. orange lemma...	Oo		23
6. Presence vs. absence of waxy bloom on stem and head.................	Wh_1wh_1	Ww	23
7. Absence vs. presence of waxy bloom on head.....	Wh wh		23
Black vs. white glumes (Bb) independent of:			
1. General vs. restricted pubescense on outer glume	Pbg pbg	Ss	22

*Figures refer to "Literature Cited", p. 62.

TABLE 3.—*Continued.*

Linkages	Recommended symbol	Previous symbol used	Authority*
2. Extended vs. narrow outer glumes	Ww	Ee	22
3. Hulled vs. naked caryopsis	Nn		40, 7, 8, 21
4. Red vs. white pericarp	Re re	Re	7
5. Purple vs. white lemma	Pp		7
6. White vs. orange lemma	Oo	Br br	7
7. Blue vs. white aleurone	Bl bl		7
8. Hoods vs. awns	Kk		40, 30, 7, 21
9. Inhibition of purple and red pericarp (2 factors)	Jj, J_1j_1	Ii, Jj	7
10. Green vs. albino seedlings	A_ca_c	Aa	40, 30
11. Long vs. short-haired rachilla	Ss	Ll	40, 30, 49, 7
12. Rough vs. smooth awn	Rr		30, 49, 8, 42
13. Green vs. albino	Aa		8
14. Normal vs. brachytic	Br br		39
15. Green vs. albino seedlings	$A_{c2}a_{c2}$		47
16. Green vs. albino seedlings	A_na_n		47
17. Green vs. xantha seedlings	X_sx_s		47
18. Fertile intermedium vs. non-intermedium	I^hi		29
19. Green vs. virescent seedlings	Yy		48
20. Green vs. orange seedlings	Or or		48
21. Branched vs. unbranched styles	Uu	Gg,G′g′,G″g″	42
22. Normal vs. reduced lateral spikelet appendages on the lemma	Lr lr		29
General vs. restricted pubescence on outer glume (Pbg pbg) independent of:			
1. Rough vs. smooth awn	Rr		22
2. Long vs. short-haired rachilla	Ss	Ll	22
Green vs. albino seedlings (A_ta_t) independent of:			
1. Green vs. chlorina seedlings	F_cf_c		41
2. Green vs. albino seedlings	A_ca_c		40
3. Green vs. xantha seedlings	X_cx_c		40
4. Long vs. short-haired rachilla	Ss		40
5. Green vs. virescent seedlings	Yy		48
Hulled vs. naked caryopsis (Nn) independent of:			
1. Hooded vs. awned	Kk		21, 22, 40, 7
2. Long vs. short-haired rachilla	Ss	Ll	22, 40, 7
3. Green vs. albino seedlings	A_ca_c		40
4. Green vs. chlorina seedlings	F_cf_c		44
5. Green vs. albino seedlings	A_ba_b		44
6. Green vs. albino seedlings	Aa		8
7. Tall vs. short	Hh		35
8. Dense vs. lax	Ll		35

*Figures refer to "Literature Cited", p. 62.

TABLE 3.—*Continued.*

Linkages	Recommended symbol	Previous symbol used	Authority*
9. Early vs. late	Ea ea	Xx, Yy	35
10. Blue vs. white aleurone	Bl bl		7
11. White vs. orange lemma	Oo	Br br	7
12. Purple vs. white-veined lemma (2 factors)	P_cp_c, P_ep_e	Cc, Fe	7
13. Green vs. albino seedlings	A_na_n		47
14. Green vs. xantha seedlings	X_sx_s		47
15. Fertile intermedium vs. non-intermedium	I^hi		29
16. Rough vs. smooth awn	Rr		8
17. Normal vs. reduced lateral spikelet appendage of the lemma	Lr lr		29
18. Green vs. virescent seedlings	Yy		48
19. Green vs. orange seedlings	Or or		48
Green vs. albino seedlings ($A_{c2}a_{c2}$) independent of:			
1. Green vs. virescent seedlings	Yy		48
2. Fertile intermedium vs. non-intermedium	I^hi		29
3. Hoods vs. awns	Kk		47
4. Green vs. chlorina seedlings	F_cf_c		41
5. Green vs. albino seedlings	A_ca_c		41
Hoods vs. awns (Kk) independent of:			
1. Long vs. short-haired rachilla	Ss		40, 30, 7
2. Green vs. albino seedlings	A_ca_c	Aa	44, 30
3. Green vs. albino seedlings	A_ba_b		44
4. Green vs. albino seedlings	Aa		8
5. Green vs. yellow seedlings	$X_{c2}x_{c2}$		41
6. Green vs. virescent seedlings	Y_cy_c		41
7. Green vs. chlorina seedlings	F_cf_c		41
8. Straight vs. curved peduncle	Cr cr		7
9. Red vs. white pericarp	Re re	Oo	7
10. Purple vs. white lemma	Pp		7
11. White vs. orange lemma	Oo	Br br	7
12. Purple vs. white-veined lemma (2 factors)	P_ep_e, P_fp_f	Ee, Ff	7
13. Restricted vs. susceptibility to mildew (*Erysiphe graminis hordei*)	Ml ml		57
14. Green vs. albino seedlings	A_na_n		47
15. Green vs. xantha seedlings	X_sx_s		47
16. Normal vs. reduced lateral spikelet appendage of the lemma	Lr lr		29
17. Green vs. virescent seedlings	Yy		48
18. Green vs. orange seedlings	Or or		48

*Figures refer to "Literature Cited", p. 62.

TABLE 3.—*Continued.*

Linkages	Recommended symbol	Previous symbol used	Authority*
Blue vs. non-blue aleurone (Bl bl) independent of:			
1. Long vs. short-haired rachilla	Ss		7, 42
2. Green vs. albino seedlings	$A_{t3}a_{t3}$	$Alb^{t}alb^{t}$	7
3. Straight vs. curved peduncle	Cr cr		7
4. Green vs. virescent seedlings	Yy		48
5. Green vs. xantha seedlings	X_cx_c		42
Intermedium vs. non-intermedium (I^hIi) independent of:			
1. Green vs. chlorina seedlings	F_cf_c		44
2. Green vs. xantha seedlings	X_sx_s		47, 29
3. Purple vs. white straw	Pr pr		44
4. Green vs. orange seedlings	Or or		48
5. Dense vs. lax	L_al_a		65
6. Long vs. short-haired rachilla	Ss		29
Rough vs. smooth awn (Rr) independent of:			
1. Purple vs. white pericarp	Pp		8
2. Green vs. albino	Aa		8
3. Green vs. albino	A_ca_c		30
4. Resistance vs. susceptibility to *P. graminis tritici*—forms 17, 38, and 49	Tt		38
5. Toothed vs. untoothed lemma	Gg		67
6. Presence vs. absence of waxy bloom on leaves	Wl wl		58
7. Green vs. xantha seedlings	X_sx_s		47
8. Green vs. virescent seedlings	Yy		48
Long vs. short-haired rachilla (Ss) independent of:			
1. Green vs. albino seedlings	A_ca_c	Aa	40, 30
2. Green vs. albino seedlings	$A_{t3}a_{t3}$	$Alb^{t}alb^{t}$	7
3. Green vs. albino seedlings	Aa		8
4. Green vs. chlorina seedlings	F_cf_c		42, 44
5. Rough vs. smooth awn	R_1r_1		42
6. Straight vs. curved peduncle	Cr cr		7
7. Purple vs. white pericarp	Pp		8
8. Purple vs. white-veined lemma	P_ep_e, P_fp_f	Ee, Ff	7
9. Red vs. white pericarp	Re re	Rr	7
10. Complementary factors inhibiting pericarp color	Jj, J_1j_1	Jj, Ii	7
11. Toothed vs. untoothed lemma	Gg		67
12. Long vs. short internode	L_4l_4		67
13. Long vs. short internode	L_5l_5		67

*Figures refer to "Literature Cited", p. 62.

TABLE 3.—*Continued.*

Linkages	Recommended symbol	Previous symbol used	Authority*
14. Resistance vs. susceptibility to mildew (form 3)...	$Ml_a ml_a$		5
15. Resistance vs. susceptibility to mildew (form 3)...	$Ml_h ml_h$	Hh	3
16. Resistance vs. susceptibility to mildew (form 3)...	$Ml_g ml_g$	Gg	4
17. Presence vs. absence of waxy bloom on leaves...	Wl wl		58
18. Green vs. albino seedlings..	$A_n a_n$		47
19. Green vs. xantha seedlings	$X_s x_s$		47
20. Normal vs. reduced lateral spikelet appendages on the lemma............	Lr lr		29
21. Dense vs. lax............	$L_a l_a$		65
22. Green vs. virescent seedlings.................	Yy		48
Green vs. xantha seedlings ($X_e x_e$) independent of:			
1. Green vs. virescent seedlings.................	Yy		42
2. Green vs. yellow seedlings..	$X_{e2} x_{e2}$		41
3. Green vs. virescent seedlings.................	$Y_e y_e$		41
4. Green vs. virescent seedlings.................	Yy		47, 42
5. Normal vs. reduced lateral spikelet appendages on the lemma............	Lr lr		29
6. Green vs. chlorina seedlings	$F_e f_e$		41
Green vs. albino seedlings ($A_e a_e$) independent of:			
1. Green vs. yellow seedlings..	$X_{e2} x_{e2}$		41
2. Green vs. virescent seedlings.................	$Y_e y_e$		41
3. Green vs. orange seedlings	Or or		48
4. Green vs. chlorina seedlings	$F_e f_e$		41
Green vs. xantha seedlings ($X_s x_s$) independent of:			
1. Fertile intermedium vs. non-intermedium.......	$I^h i$		29
2. Green vs. virescent seedlings.................	Yy		48
3. Green vs. chlorina seedlings	$F_e f_e$		47
Green vs. albino seedlings ($A_n a_n$) independent of:			
1. Green vs. orange seedlings	Or or		48
2. Green vs. chlorina seedlings	$F_e f_e$		47
Green vs. albino seedlings ($F_e f_e$) independent of:			
1. Green vs. yellow seedlings..	$X_{e2} x_{e2}$		41

*Figures refer to "Literature Cited", p. 62.

TABLE 3.—*concluded.*

Linkages	Recommended symbol	Previous symbol used	Authority*
2. Normal vs. reduced lateral spikelet appendages on the lemma.	Lr lr		29
Green vs. virescent seedlings ($Y_c y_c$) independent of:			
1. Green vs. xantha seedlings	$X_s x_s$		47
2. Green vs. albino seedlings. .	$A_n a_n$		47
3. Green vs. virescent seedlings.	Yy		48
Purple vs. white-veined lemma ($P_e p_e$) independent of:			
1. Purple vs. white-veined lemma.	$P_f p_f$		7
2. Complementary factor inhibiting purple and red pericarp color.	Jj, $J_i j_i$	Jj, Ii	7
Purple vs. white-veined lemma ($P_e p_e$ $P_f p_f$) independent of:			
1. Complementary factor inhibiting purple and red pericarp color.	Jj, $J_i j_i$	Jj, Ii	7
Resistance vs. susceptibility to mildew (form 3) ($Ml_a ml_a$) independent of:			
1. Resistance vs. susceptibility to mildew (form 3). . .	$Ml_g ml_g$	Gg	5
2. Resistance vs. susceptibility to mildew (form 3). . .	$Ml_h ml_h$	Hh	5
Resistance vs. susceptibility to mildew (form 3) ($Ml_k ml_k$) independent of:			
1. Resistance vs. susceptibility to mildew (form 3). . .	$Ml_g ml_g$	Gg	5
2. Resistance vs. susceptibility to mildew (form 3). . .	$Ml_h ml_h$	Hh	5
Resistance vs. susceptibility to mildew (form 3) ($Ml_g ml_g$) independent of:			
1. Resistance vs. susceptibility to mildew (form 3). . .	$Ml_h ml_h$	Hh	5

*Figures refer to "Literature Cited", p. 62.

FACTORS SHOWING INDEPENDENT INHERITANCE

The factor pairs showing independent inheritance are listed in Table 3. Several characters in each linkage group are listed and the various characters which have been studied and found to be independent are given. If the factor pair in group II is found to be independent of, say, (Vv) non-six-rowed vs. six-rowed in group I, then non-six-rowed vs. six-rowed will not be listed as being independent of this

factor pair when the factor pair is listed in relationship to other independently inherited characters. Thus, when a character is listed as independent of another character, this relationship will not be shown again. The main character pairs are listed in the order in which they occur in the linkage groups in Table 2.

POLYSOMICS AND POLYPLOIDS

A few barley strains have been found or produced in which the chromosome number is greater or smaller than the normal diploid number of 14. The various types reported are listed in Table 4.

TABLE 4.—*Polysomics and polyploids listed by workers on barley genetics.*

Type	Variety	How produced	Authority*
1. Trisomic	Specific chromosome unknown	Spontaneous	27
2. Haploid	*H. distichum*	Spontaneous	59, 24
3. Tetraploid	Opal B.	Heat	33
Tetraploid	Viner 01163	Heat	25
Tetraploid	Europeum 0353/135	Heat	25
Tetraploid	Calchicum 10/30	Heat	26
Tetraploid	Kolkhoy	Heat	26
Tetraploid	Alpha	Colchicine	10
Tetraploid	Wisconsin Barbless	Colchicine	10
Tetraploid	Everest	Colchicine	——†
Tetraploid	Big Boy	Spontaneous	——‡
Tetraploid	O.A.C. 21	Heat	37

*Figures refer to "Literature Cited", p. 62.
†Unpublished. Harland Stevens. Aberdeen, Idaho.
‡Unpublished. U.S.D.A., B.P.I. Washington, D. C.

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INTERFERENCE OF AMMONIA, RELEASED FROM SUGAR BEET SEED BALLS, WITH LABORATORY GERMINATION TESTS[1]

MYRON STOUT AND BION TOLMAN[2]

EXPERIMENTAL work conducted by the U. S. Dept. of Agriculture during the past 4 years has shown that some lots of sugar beet seed contain substances which are toxic to the germinating seed.[3] The toxic agent has been shown to be free ammonia hydrolyzed from the organic nitrogen compounds of the seed ball during the process of germination.[4]

The rules for seed testing of the Association of Official Seed Analysts,[5] and also the official rules under the Federal Seed Act,[6] recommend soaking beet seed for 2 hours before testing, but do not make recommendations as to quantity of water to be used. In many commercial laboratories, this precautionary soaking procedure has been omitted. Recently, several inquiries have been made by commercial sugar beet seed producers concerning the cause of low laboratory germination tests on seed that was apparently well filled as shown by high cracking test and weight per bushel. In these instances improvement of germination by the usual gravity methods of recleaning was impossible. However, when these seed lots were thoroughly washed in running water prior to testing, the germination percentages approximated the germinability that was indicated by cracking tests.

The economic aspect of the problem is evidenced by the fact that several lots of sugar beet seed, later shown to be of high quality, were unacceptable to the commercial trade on the basis of laboratory germination tests made without soaking or washing of the seed balls.

The importance of washing the seed balls prior to making the germination test was strikingly shown in the following experiment with six different seed lots. These seed lots were selected from commercial seed sources because of the wide spread between the germination percentages obtained in the laboratory and the expected germinability indicated by cracking tests. A small quantity of seed from each one of the six lots was washed in running tap water for 24 hours and air dried. The germination of the washed seed from each lot was then compared with untreated seed. Germination tests were conducted by five different methods, as follows: (1) On a cotton substratum in petri dishes; (2) in sand in shallow pans; (3) between moist blotters; (4) in soil in the greenhouse, planting depth ½ inch; and (5) in the

[1]Contribution from Salt Lake City Laboratory, Division of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication October 30, 1940.

[2]Assistant Physiologist and assistant Agronomist, respectively.

[3]TOLMAN, BION, and STOUT, M. Toxic effect on germinating sugar beet seed of water-soluble substances in the seed ball. (Submitted for publication).

[4]STOUT, M., and TOLMAN, B. Ammonia and other factors affecting seed germination, with special reference to the toxic effects of sugar beet seed ball extracts. (Submitted for publication).

[5]Rules and Recommendations for Testing Seeds. U. S. D. A. Circular 480.

[6]U. S. D. A. Service and Regulatory Announcement No. 156.

field in clay loam soil of better than average fertility, with the seeds dibbled in ¾ inch deep and 3 inches apart in the row on April 15, 1940, the treatments being replicated four times and each replication consisting of a planting of 100 seed balls of both washed and untreated seed of each of the six lots tested.

The germination counts made on the 12th and 17th days are shown in Table 1. It is evident that in petri dishes where the ammonia released from nitrogenous compounds was held in direct contact with the seed balls greatest inhibition of germination occurred. From Fig. 1 it can be seen that many of the sprouts from the unwashed seed were actually killed. Less severe but somewhat similar inhibition of germination and sprout injury were noticed on the tests where unwashed seed was germinated on blotters and in sand. It can be seen from the data in Table 1 that very little difference was evident between washed and unwashed seed when germinated in soil.

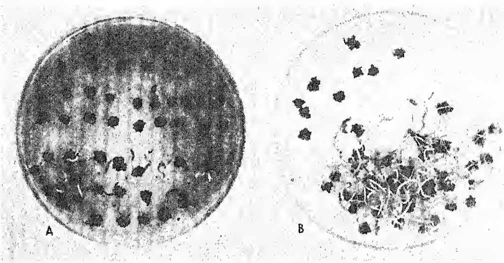

FIG. 1.—A comparison of germination and sprout condition of untreated and washed sugar beet seed balls. A, untreated seed balls; B, sugar beet seed balls washed in running water for 24 hours. The samples were placed to germinate on cotton in petri dishes.

Seed lot No. 9307 is of special interest in this respect. Unwashed seed germinated by customary laboratory methods in sand and on blotters gave germination percentages of 55 and 71, respectively. The germination report as given by a commercial seed laboratory was 75%, yet washed samples of this seed lot germinated 97 and 96% in sand and on blotters and averaged 98% in greenhouse soil. Under field conditions, with some soil crusting, 88% of the seed balls developed healthy plants.

Literature relative to the effect of washing or presoaking seed prior to planting is too extensive to be covered in this brief report. Several Russian workers claim to have obtained large increases in yield and sucrose percentage by presoaking or by pregerminating the seed at temperatures from 3° to 22° C before planting. Other workers have shown little or no benefits from such treatments.

TABLE 1.—*Germinations obtained with washed and untreated test samples from six lots of sugar beet seed.**

Variety and lot number	Cracking test, %	Weight per bushel, lbs.	Treatment	Germination counts after: 12 days — Germinated on cotton in petri dishes, %	12 days — Germinated in sand, %	12 days — Germinated on blotters, %	12 days — Germinated in greenhouse soil, %	17 days, field planted, %
U. S. 12 (9301)	87	22.5	Washed	86	93	86	92	73
			Untreated	50	54	65	89	67
			Difference	36	39	21	3	6
U. S. 15 (9302)	76	17.0	Washed	60	66	72	70	56
			Untreated	36	47	64	62	55
			Difference	24	19	8	8	1
U. S. 15 (9304)	95	22.0	Washed	84	93	93	90	87
			Untreated	57	78	76	89	84
			Difference	27	15	17	1	3
U. S. 200 (9307)	99	20.5	Washed	82	97	96	97	87
			Untreated	35	55	71	99	89
			Difference	47	42	25	−2	−2
U. S. 215 (9308)	99	21.0	Washed	91	99	98	98	87
			Untreated	61	87	91	96	88
			Difference	30	12	7	2	−1
U. S. 33 (9309)	93	16.5	Washed	92	87	97	92	83
			Untreated	42	76	63	93	74
			Difference	50	11	34	−1	9
Mean difference				35.7	23.0	18.7	1.8	2.7

*Results with several methods of germination are compared with those obtained by field plantings.

TABLE 2.—*Acre yields of roots and sucrose percentages obtained in replicated tests in which washed and untreated seed of two sugar beet varieties were compared as to their effects on the crop; tests conducted in Utah and Idaho in 1937.*

Treatment	Granger, Utah		Garland, Utah		Sevier Valley, Utah		Buhl, Idaho*		Aberdeen, Idaho†		Average all locations	
	Acre yield of roots, tons	Sucrose, %	Acre yield of roots, tons	Sucrose, %	Acre yield of roots, tons	Sucrose, %	Acre yield of roots, tons	Sucrose, %	Acre yield of roots, tons	Sucrose, %	Acre yield of roots, tons	Sucrose, %
					U. S. 10							
Washed	23.4	15.98	30.7	16.12	14.2	16.44	12.11	17.18	17.70	17.25	19.62	16.59
Untreated	23.1	15.96	29.5	16.23	15.7	16.53	12.01	17.23	17.18	17.57	19.50	16.70
					U. S. 12							
Washed	23.7	15.54	28.4	15.93	15.4	15.66	10.61	17.84	16.14	17.16	18.85	16.43
Untreated	23.6	15.49	27.8	15.84	15.0	15.72	10.53	17.54	16.53	16.95	18.69	16.31
Difference required for significance‡	1.0	0.50	2.4	0.78	2.2	0.68	2.60	0.62	—	—	—	—
Replications	24		4		4		12		4		48	

*From variety test conducted by Albert Murphy, Division of Sugar Plant Investigations, Twin Falls, Idaho.
†From variety test conducted in cooperation with Idaho Experiment Station.
‡Calculated for odds of 19 : 1.

The writers demonstrated differences in rate of seedling emergence in favor of washed seed, but it has already been shown by data in Table 1 that comparable stands were obtained from the washed and unwashed seed. Extensive tests in widely separated areas demonstrated that any apparent early advantage of the washed seed was not reflected at harvest time by yield or sucrose percentage (Table 2).

In the laboratory tests, two principal results were obtained by washing the seed. Germination rate was increased and the total germination percentage was raised to a point comparable with that of soil germination. Experimental work has shown that the benefit derived from washing is due to removal from the seed ball of soluble organic nitrogen compounds from which the toxic agent, free ammonia, is released during germination.

Since the purpose of laboratory tests is to forecast field performance of seed and since laboratory tests are the usual and accepted method of evaluating seed lots, it is inadvisable that factors which have little or no effect in the field should be allowed to so interfere with laboratory tests that they fail in the purpose for which they are conducted.

CONCLUSIONS

Obviously, the requirements of the Official Seed Analysts for soaking sugar beet seed prior to testing should be followed. Further studies should also be made to determine what modifications of practice or specifications as to quantity of water, in proportion to the sample, should be recommended. Until adequate soaking or washing of seed in running water is made a part of the germination procedure, it would seem advisable that the cracking tests be made on all low or questionable samples. If there is any great difference between the germination percentage and the percentage of filled seed balls as shown by the cracking test, the samples should be washed in running water for at least 6 hours, or otherwise treated, and a second series of germination tests run to make sure that water-soluble substances in the seed ball are not a factor inhibiting germination.

This does not mean that all seed lots give much higher germination tests in the laboratory as a result of being washed but, where germination tests differ widely from cracking tests, a frequent cause of the discrepancy is removed by thorough washing of the seed before germination tests are started.

THE MINNESOTA METHOD OF SEED INCREASE AND SEED REGISTRATION FOR HYBRID CORN[1]

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THE development of hybrid corn has created many problems relative to the release of inbred lines and the production of seed of inbred lines and of first crosses for those hybrids developed by experiment stations. Various methods of seed production have been tried. In Minnesota the seed of inbred lines and of first crosses has been increased by the Minnesota Agricultural Experiment Station in cooperation with the Minnesota Crop Improvement Association. The present paper will discuss the various methods of seed increase that have been tried at Minnesota and outline the plan now in use.

DEVELOPMENT OF EXPERIMENT STATION HYBRIDS

The first hybrid seed stocks were released by the Minnesota Experiment Station to seed growers in 1930 when 24 acres were allotted to 24 farmers. These releases were made to members of the Minnesota Crop Improvement Association, an organization which cooperates with the experiment station in the registration and certification of recommended varieties of farm crops.

From 24 acres in 1930 the industry expanded to 6,300 acres of commercial crossing plots of experiment station or "Minhybrid" varieties in 1939. The record of this expansion from 1930 is as follows:

Year	Number of acres of parent stocks	Number of acres of commercial crosses
1930	8.7	24
1931	10.0	191
1932	10.5	55
1933	10.5	260
1934	12.7	372
1935	30	406
1936	70	703
1937	116	820
1938	420	3,000
1939	100	6,300
1940	160	3,789

COOPERATIVE RELATIONSHIPS

The Experiment Station through the Division of Agronomy and Plant Genetics in cooperation with the Minnesota Crop Improvement Association has assumed the task of increasing hybrid seed

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stock. The financing of this work is made possible through a revolving fund maintained by the sale of pure seed of all kinds, including hybrid seed stocks. Policies of increase and distribution are established by a Corn Committee composed of six members of the Experiment Station working on the corn projects. While the work has been carried out by the Experiment Station, the Minnesota Crop Improvement Association has cooperated in the increase by advising regarding their probable needs and through the work of individual members of the Association who have furnished isolated seed plots and who have made increases of seed stocks under contract with the Experiment Station.

METHODS OF SEED INCREASE FIRST USED

Beginning about 1930 all inbred lines used in the commercial crosses that had been placed on the recommended list of the Minnesota Agricultural Experiment Station were increased to a limited extent from year to year by hand-pollination.

The more extensive increases were made in isolated plots without controlled hand-pollination. Due to the fact that seed supplies of the inbred lines were limited, the first single cross increases were made at the Central Experiment Station, St. Paul, and at the Southeast Experiment Station at Waseca. Some of the inbred lines first used were not especially productive. To obtain single crossed seed and also seed of the inbred lines, reciprocal crosses were made and the male parent harvested in the single cross plots. In the plots where double or three-way crossed seed was produced, advanced generation single cross or inbred seed was harvested from the male rows.

Although the plan just described utilized the seed stock to the fullest extent, it was not possible to maintain the lines and crosses in as pure condition as seemed desirable. The use of seed from the male rows in crossing plots was then discontinued both for inbred lines and single crosses.

The method next adopted for inbred lines as well as for advanced generation single crosses was the use of isolated plots of one to two acres each. For inbred lines this consisted of planting individual rows from single selfed or sib-pollinated ears. These "ear-to-row" plots were inspected prior to pollination and any off-type or undesirable rows removed. The remaining rows were harvested separately and inspected on the ear. "Ear-to-row" cultures of the desired type were then bulked. Bulk single cross seed was planted in isolated plots to obtain advanced generation single cross seed. These plots were also inspected prior to pollination and any off-type plants removed. This method is still used for obtaining seed of the advanced generation single crosses. However, the isolated plot method for inbred lines has been discontinued. In corn producing sections it was difficult to obtain satisfactory isolation for these small plots. Due to the fact that some of the lines were weak pollen producers, there was considerable mixture from off-pollination even in well-isolated plots.

PRESENT METHODS OF SEED INCREASE

The difficulties encountered in the first methods used were due partially to inherent weakness in a few inbred lines, principally, perhaps, insufficient pollen production so that the lines were subject to cross-pollination to a certain extent. This led to impurities in the inbred parents themselves. It seemed probable that the lines that had been inbred for 14 to 16 years were progressively less vigorous as they approached more complete homozygosity. Alternate selfing and crossing between selfed cultures of the inbreds and constant selection, a plan adopted more recently, should lead to the maintenance of inbred lines in a state of the necessary relative homozygosity without reducing them by continued self-pollination to a more complete state of homozygosity. The plan now in use will be outlined in detail.

Hand-crossed and selfed seed of all inbred lines needed in the corn program is planted each year in foundation plots at both the Southeast and Central Stations. The crop risk is distributed as much as possible by planting at two stations with several dates of planting at each location. Sufficient selfed ears are produced to provide the necessary seed that is needed the following year in the crossing plots where single crosses are produced. The selfed ears are inspected both before and after drying.

The seed is harvested and dried in fine-meshed bags in tray driers. Twenty to 30 individual representative selfed ears of each culture are saved and the balance of the selfed seed bulked to use for producing single crosses. Short "ear-to-row" cultures from 20 to 30 selfed ears of each inbred are planted also in the foundation plot. Hand crosses are made between the individual ear cultures obtaining several crossed ears from each combination of "ear-to-row" cultures as follows: 1 × 2, 2 × 3, 3 × 4, etc., where 1 to 4, etc., represent the "ear-to-row" cultures of each of the inbred lines, respectively. The hand-crossed ears in each culture are examined and desirable crosses are bulked using representative cultures. The crossed bulked seed is used the following year as the parental source for the rather extensive hand selfing program that furnishes the major source of selfed seed for single cross increases. In some seasons it is necessary to use hand controlled sib-pollination when self pollination for any reason in some lines does not prove feasible. The plan then consists of alternately producing selfed and crossed seed for each inbred line.

The major features of the plan may be summarized briefly as follows: When an inbred line seems relatively homozygous, sufficient selfed seed of each inbred is produced each year to plant the necessary single cross plots the following year. The seed planted for the selfing plot is obtained the preceding year from hand-pollinated crosses made by crossing the progeny of "ear-to-row" cultures within the inbred lines produced from selfed ears.

SINGLE CROSS INCREASES

The rapid increase in demand for hybrid parent stocks made it necessary to produce the larger part of the single crosses with individ-

ual farmers. Two types of contracts have been used, one calling for an acre rental fee and the other on the basis of production usually by pound units. On the acre basis it did not appear that growers were sufficiently interested in all cases to place the work on a desirable basis. There was no great incentive to produce a high yield. On the other hand, the yields of the single crosses were unpredictable, and it was difficult to arrive at a satisfactory price on the pound basis.

This year a new form of contract has been used with the majority of the growers. The grower is permitted to retain a share of the seed stocks produced for his part in the contract. The balance of the seed is then turned over to the Experiment Station for sale to other growers. Single cross producers are allowed to exchange seed stocks by making the necessary arrangement with the seed certification official of the Minnesota Crop Improvement Association who is a member of the Minnesota Experiment Station and the senior writer of this article. Small plots used for the increase of advanced generation seed are contracted on the acre rental or unit payment plan.

During the past season it was possible to examine the first results of the new methods of seed increase. All the single crossing plots were planted with hand-pollinated seed. The purity of the parent lines was highly satisfactory. Actual counts showed the percentage of off-type plants to run on an average of about 0.25%, or 1 to 400. Any rogues present were removed prior to tasseling.

From previous experience it is believed that it will be necessary to provide hand-pollinated seed every year for the single cross plots. From indications to date, the methods of increase outlined in this article should provide both the purity and quantity of inbred seed desired.

METHODS OF SEED REGISTRATION

The Minnesota Pure Seeds Act does not require registration of hybrid seed sold in the state; however, growers obtaining Minhybrid seed stocks agree to submit their work to inspection by the Minnesota Crop Improvement Association. The latter organization is recognized as the seed registration and certification organization for hybrid corn in the state. This organization is a member of the International Crop Improvement Association and is maintained by legislative funds and inspection fees.

At the present time two general classes of hybrid corn seed are recognized by the Association, namely, Registered and Certified. There are two grades of Registered seed, No. 1 or blue tag and No. 2 or red tag. Standards of germination, purity, grading, and moisture separate the two grades. Seed qualifying for registration must have been produced from seed stocks obtained from the experiment stations of Wisconsin or Minnesota. The term, certified seed, applies to seed of commercial hybrids where the inbred lines and single crosses are controlled by the seed company. Commercial hybrids eligible for certification must have been tested for 3 years in the state yield test and must have proved satisfactory in yield and other characters. The producer must file an affidavit with the Minnesota Crop Improve-

ment Association that the parent lines used in the crossing plot are of the same breeding and purity as those parent lines used in the hybrid tested in the official yield trials. Field inspection of the crossing plots for both Registered and Certified seed is on the same basis. Inspection both in the field and laboratory is necessary for all grades and classes of pure seed recognized by the Association.

EFFECT OF SEED TREATMENT ON STANDS OF SOME FORAGE LEGUMES[1]

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RELATIVELY little has been done with respect to the possible effects of seed treatment on stands of various clovers and other forage legumes. A brief abstract by Bucholtz (2)[3] describes the effect of an organic mercury dust as a seed treatment on stands of alfalfa, white sweet clover, alsike clover, white dutch clover, red clover, and lespedeza. Horsfall (6, 7) states that zinc oxide gave better stands than red copper oxide when used on the seed of alfalfa and clover. The purpose of this paper is to present results obtained in the greenhouse with various seed treatments on stands of forage legumes of the general *Lespedeza*, *Lotus*, *Medicago*, *Melilotus*, and *Trifolium*.

MATERIALS AND METHODS[4]

Eighteen species of forage legumes were used. The fungicides tested were 5% ethyl mercury phosphate (New Improved Ceresan), 2% ethyl mercury chloride (2% Ceresan), zinc oxide (Vasco 4), cuprous oxide (Cuprocide), and an organic sulfur compound (DuBay 1286A). Cuprocide and Vasco 4 were selected as representatives of cuprous oxide and zinc oxide on the basis of results of Anderson, Kadow, and Hopperstead (1) and of Cook (3), respectively.

Seed of the various species, when necessary, were scarified with sand-paper to facilitate germination before treatment with the various fungicides. The seed were treated by adding an excess of the fungicides, shaking, and screening off the excess material. In the dosage studies, the seed were weighed, treated as above, and then reweighed, the difference between the two weights being the quantity of dust retained on the seed. From these weights, the proportionate dosages for each species were calculated and added to the seed without dilution. Three replications of 1,000 seed each were used in a test, except where otherwise noted. Over a million seed were planted in the tests.

Except in one series of experiments the plantings were made in non-sterilized field soil in flats in the greenhouse. In this one series the soil was sterilized 1 to 2 hours at 15 to 20 pounds pressure in an autoclave. Watering was done whenever necessary to maintain soil moisture at a relatively high level. Plants which damped off after emerging were removed and recorded every other day. Stand counts were made after post-emergence damping off had practically ceased, usually 10 to 15 days after planting.

All plantings were randomized to permit analysis of variance according to the method of Fisher (4). The percentage of post-emergence damping off was calculated by dividing the number of plants which damped off after emergence by the total number of plants emerging. These data were analyzed both as percent-

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[2]Agent and Director, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 82.

[4]Acknowledgement is made to the various companies furnishing the fungicides and to Dr. E. A. Hollowell for furnishing seed of the various species tested.

ages and after transferring to degrees with the table given by Fisher and Yates (5) for that purpose. Similar results were obtained with the two methods.

EXPERIMENTAL RESULTS

From the data in Table 1 it may be seen that the use of New Improved Ceresan resulted in the greatest increases in stands compared with checks when used on the seed of *Lespedeza stipulacea*, *Medicago hispida*, *M. lupulina*, *Melilotus alba*, *M. indica*, *M. officinalis*, *Trifolium alexandrinum*, *T. hybridum*, *T. incarnatum*, *T. pratense*, *T. repens*, and *T. repens* (*Ladino*). *T. subterraneum* was stunted by New Improved Ceresan at the maximum dosage used, Ceresan giving the best results. *Trifolium fragiferum* was helped equally by New Improved Ceresan and Vasco 4. None of the five seed treatments was beneficial with *Lotus corniculatus*, *Trifolium dubium*, *T. glomeratum*, and *T. procumbens*. *Trifolium glomeratum* seemed to be injured by Ceresan and cuprous oxide. Where increases in stand were obtained with New Improved Ceresan, they ranged from over 3,200% with *Trifolium alexandrinum* to 16% with *Trifolium fragiferum* as compared with stands from untreated seed.

To determine whether the relatively poor results with some of the fungicides were due to toxicity because of too heavy applications, treated and untreated seed of 15 of the legumes were planted in sterilized soil. The results (Table 2) indicate that dosage injury, with the exception of *Trifolium subterraneum* treated with New Improved Ceresan, was not the cause of the differences among seed treatments. Slight, but statistically significant, increases in stand were obtained with some of the treatments in the sterilized soil. Whether these increases were of real significance is not known.

In Table 3, the average relative efficiency of the various seed treatments with respect to increasing emergence and the control of post-emergence damping off are given with 14 and 13 species, respectively. The use of New Improved Ceresan proved to be most efficient, the average emergence obtained from its use being 60.4% as compared to 28.1% for the check. Ceresan, Vasco 4, and Du Bay 1286A, in the order given, increased emergence somewhat. Cuprous oxide was of little or no value. New Improved Ceresan was by far the best fungicide with respect to controlling post-emergence damping off. Vasco 4 gave some control. Fig. 1 shows the effect of seed treatment with New Improved Ceresan as compared to check on stand of *Trifolium incarnatum.*

A second lot of cuprous oxide was tested on seed of *Trifolium incarnatum*, as the lot of the chemical used in the original experiments was over a year old. The results (Table 4) were similar to those obtained in the previous experiment. Repeated tests of cuprous oxide were made in comparison with New Improved Ceresan on *Melilotus alba*, *M. officinalis*, *Trifolium pratense*, and *Lespedeza stipulacea*. The results showed cuprous oxide to be inferior to New Improved Ceresan.

The tests with New Improved Ceresan were repeated several times with seeds of the species responding most favorably to treatment. *Melilotus suaveolens* not included previously was tested also. *Trifolium*

TABLE 1.—*Effect of five seed treatments on stand of 17 species of forage legumes.*

Species	Final stand based on 3,000 seed to treatment, %						Differences necessary for significance at	
	Check	New Improved Ceresan	Ceresan	Vasco 4	DuBay 1286A	Cuprous oxide	1% point	5% point
Lespedeza stipulacea Maxim.	44.7	**64.7****	50.8	35.8	49.3	41.5	9.2	6.5
Lotus corniculatus L.	50.5	49.2	44.9	56.8	48.6	55.5	10.6	7.5
Medicago hispida Gaertn.†	8.2	**19.3**	9.9	*13.8*	11.6	11.3	6.3	4.4
Medicago lupulina L.	2.5	**61.7**	4.2	6.4	3.7	3.3	14.0	9.8
Melilotus alba Desr.	12.9	**53.2**	**35.1**	16.2	*20.0*	13.8	10.0	7.0
Melilotus indica All.	12.2	**48.5**	**40.4**	25.1	25.5	10.4	21.8	15.3
Melilotus officinalis (L.) Lam.	15.8	**61.0**	20.7	20.5	17.6	11.3	11.4	8.0
Trifolium alexandrinum L.†	0.5	**16.2**	0.8	2.2	1.5	1.3	6.3	4.4
Trifolium dubium Sibth.	63.3	67.8	62.3	68.1	62.3	60.1	8.1	5.7
Trifolium fragiferum L.	54.3	*63.1*	58.7	*64.1*	61.1	58.0	12.2	8.6
Trifolium glomeratum L.	25.2	23.2	*21.1*	25.3	24.9	*21.2*	5.4	3.8
Trifolium hybridum L.	51.2	**72.6**	58.1	**66.8**	53.7	48.3	14.1	9.9
Trifolium incarnatum L.	3.7	**65.4**	*13.1*	7.7	10.1	8.9	9.7	6.8
Trifolium pratense L.	7.0	**63.4**	12.3	8.6	6.2	10.1	8.3	5.8
Trifolium procumbens L.	17.8	21.0	21.6	20.8	20.8	21.9	8.1	5.7
Trifolium repens L.	20.3	**80.9**	**49.4**	**44.2**	*35.5*	29.9	16.3	14.6
Trifolium repens L. (Ladino)	47.3	**64.5**	*52.1*	**58.0**	**58.1**	**55.2**	6.5	4.6
Trifolium subterraneum L.	31.1	**60.5**‡	**72.6**	*46.5*	**53.6**	*42.6*	16.1	11.3

*Bold face figures indicate differences significant at 1% point; italicized figures indicate differences significant at 5% point.
†Seed germination low.
‡Emergence retarded.

TABLE 2.—*Effect of five seed treatments on stand of 14 species of forage legumes planted in sterilized soil.*

Species	Number of seed to treatment	Stand, %						Differences necessary for significance at 5% point
		Check	New Improved Ceresan	Ceresan	Vasco 4	Cuprous oxide	DuBay 1286A	
Lespedeza stipulacea Maxim.	400	66.8	65.5	*79.0**	70.1	70.1	*75.5*	7.2
Lotus corniculatus L.	400	43.3	42.5	40.3	39.5	42.8	47.8	8.7
Medicago hispida Gaertn.	600	24.3	23.3	*19.7*	23.7	22.8	22.8	3.4
Medicago lupulina L.	400	70.8	74.5	72.8	72.3	67.3	*78.3*	7.4
Melilotus alba Desr.	400	76.8	76.5	79.8	80.0	75.3	78.8	5.7
Melilotus indica All.	400	59.0	56.0†	62.8	*65.8*	61.0	62.3	5.6
Melilotus officinalis (L.) Lam.	400	72.5	*80.3*	71.3	*67.3*	72.5	75.0	4.0
Trifolium alexandrinum L.	600	26.7	24.0	31.5	27.7	22.8	29.2	5.7
Trifolium fragiferum L.	400	63.3	64.0	62.8	65.5	61.8	64.5	5.5
Trifolium hybridum L.	400	64.0	66.7	63.3	62.5	61.8	66.0	9.7
Trifolium incarnatum L.	400	77.3	77.5	77.3	82.0	*83.5*	80.3	5.3
Trifolium pratense L.	400	71.5	68.8	68.8	69.2	*67.3*	68.0	4.1
Trifolium repens L.	300	72.7	81.0	81.0	82.0	72.7	76.3	13.9
Trifolium repens (L. Ladino)	400	44.0	45.0	46.8	46.3	41.8	39.0	12.8
Trifolium subterraneum L.	400	74.8	*55.3*‡	77.0	75.3	75.8	76.5	5.3
Average		60.5	60.1	62.3	62.0	60.0	62.7	—

*Italicized numbers indicate significant differences from checks.
†Cotyledons slow in opening.
‡Stunting.

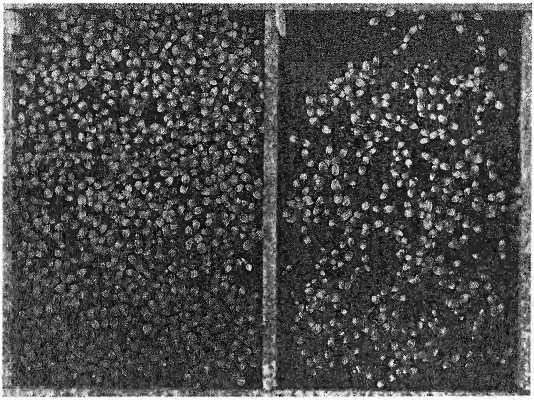

FIG. 1.—Stands resulting from seed of *Trifolium incarnatum* treated with New Improved Ceresan (left) and from non-treated seed (right).

TABLE 3.—*Effect of seed treatments on emergence and post-emergence damping off with certain forage legumes.*

	Number species included	Check, %	New Improved Ceresan, %	Ceresan, %	Vasco 4, %	DuBay 1286A, %	Cuprous oxide, %	Differences necessary for significance at	
								1% point	5% point
Emergence.....	14	28.1	60.4	41.2	36.7	36.1	30.5	3.8	2.7
Post-emergence damping off*	13	18.5	6.7	19.4	14.6	18.5	17.1	3.3	—

*Similar results were obtained when percentages were transferred to degrees according to table of Fisher and Yates (5).

TABLE 4.—*Effect of two lots of cuprous oxide and one lot of New Improved Ceresan on stands of Trifolium incarnatum.*

No. of seed to treatment	Check	Cuprous oxide 1	Cuprous oxide 2	New Improved Ceresan	Difference necessary for significance at	
					1% point	5% point
3,000	39.2	46.4	45.8	79.8	14.4	9.5

subterraneum was tested several times with Ceresan. The results obtained (Table 5) were similar to those presented in Table 1. The stands of *Melilotus suaveolens* were almost doubled with New Improved Ceresan.

TABLE 5.—*Summary of results of seed treatment of 13 species of forage legumes with New Improved Ceresan and one species with Ceresan.*

Species	Number of seed per treatment in thousands	Stand, %			Post-emergence damping off, %	
		Check	New Improved Ceresan	Differences necessary for significance at 1% point	Check	5% ethyl mercury phosphate
Lespedeza stipulacea Maxim	24	42.7	54.3	4.6	18.6	14.9
Medicago hispida Gaertu.	9	11.4	18.0	1.9	—	—
Medicago lupulina L.	15	7.0	46.8	6.2	40.0	20.0*
Melilotus alba Desr.	18	28.0	55.7	4.1	31.1	21.1*
Melilotus indica All	12	12.2	53.8	6.1	12.8	8.1
Melilotus officinalis (L.) Lam.	18	27.1	51.0	5.4	33.5	21.9*
Melilotus suaveolens Ldh.	9	43.2	76.5	4.3	9.0	1.0*
Trifolium alexandrinum L.	9	1.2	20.4	0.5	—	—
Trifolium hybridum L.	15	46.9	62.9	5.4	12.0	6.0*
Trifolium incarnatum L.	24	22.4	65.3	3.6	46.2	12.9*
Trifolium pratense L.	15	27.5	55.0	2.4	14.5	15.1
Trifolium repens L.	15	37.2	69.7	5.1	19.7	8.5*
Trifolium repens L. (Ladino)	12	47.4	58.0	5.0	—	—
			Ceresan			
Trifolium subterraneum L.	18	44.0	72.4	6.8	—	—

*F value exceeds 1% point.

The data from the dosage studies with 12 species are given in Table 6. It must be emphasized that soil type (8) and other environmental factors (3) may influence the efficacy and toxicity of the various dosages, and that the results given here were obtained from only one type of soil. The data indicate that the severity of soil infestation had an effect on the dosage necessary for maximum stands and that in some cases the highest stands occurred where there was some stunting. This may be seen in the results obtained with *Trifolium incarnatum*. In most cases dosages of 1 to 1.5% gave best results. The seed *Medicago hispida* and *Trifolium alexandrinum* held relatively little of the fungicide, the greatest application tried being 0.6% by weight which gave best results. A dosage of 1.5% with any of the species is a very heavy one.

TABLE 6.—*Effect of rate of application of New Improved Ceresan on percentage stand.*

Species	Part I: No. seeds to treatment in thousands	Part I: Per cent by weight of fungicide for maximum dosage	Part I: Maximum dosage	Part I: ½ maximum dosage	Part I: ¼ maximum dosage	Part I: ⅛ maximum dosage	Part I: Check	Part I: Differences necessary for significance at 1% point	Part I: Differences necessary for significance at 5% point	Part II: No. seed to treatment in thousands	Part II: Per cent by weight of fungicide added 1–½%	Part II: Per cent by weight of fungicide added 1%	Part II: Per cent by weight of fungicide added ½%	Part II: Per cent by weight of fungicide added Check	Part II: Differences necessary for significance at 1% point	Part II: Differences necessary for significance at 5% point	Limits of application in per cent by weight for best results
Lespedeza stipulacea Maxim.	9	3.0	70.7†	70.1	59.9	55.4	53.6	9.9	6.9	—	—	—	—	—	—	—	1.5–0.75
Medicago hispida Gaertn.*	6	0.6	17.3	15.7	—	—	13.0	2.6	1.8	—	—	—	—	—	—	—	—
Medicago lupulina L.	6	1.0	48.2	19.5	16.2	9.6	9.9	6.0	—	—	—	—	—	—	—	—	1.0
Melilotus alba Desr.	6	1.4	67.7	58.4	—	—	28.3	10.4	7.2	3	56.5	48.4	—	25.4	17.5	10.5	1.5–1.0
Melilotus indica All.	6	1.5	53.6	32.9	—	—	12.7	8.0	5.5	3	27.4	15.5	12.7	10.0	19.4	12.7	1.5
Melilotus officinalis (L.) Lam.	6	1.7	61.6†	63.7	—	—	30.1	10.5	7.3	3	50.6	37.3	—	14.3	16.5	10.0	1.5–0.85
Melilotus suaveolens Ldb.	6	1.3	77.1‡	71.3	—	—	49.2	4.9	3.4	3	65.6	61.7	48.8	36.9	15.1	10.0	1.5–1.0
Trifolium alexandrinum L*	5	0.6	17.5	3.6	—	—	1.9	7.0	4.9	—	—	—	—	—	—	—	—
Trifolium hybridum L.	6	1.2	64.0	60.6	58.9	55.7	53.7	6.0	4.4	3	61.5	59.8	44.2	49.2	13.3	8.8	1.5–0.6
Trifolium incarnatum L.	6	1.0	61.2‡	45.9	37.9	34.2	26.9	7.4	5.4	5	66.6†	48.4	43.6	35.7	20.0	14.1	1.5†
Trifolium pratense L.	6	1.0	62.8	49.2	—	—	38.1	3.5	2.4	6	49.6	38.8	30.5	31.3	14.2	10.1	1.5–1
Trifolium repens L.	6	1.2	74.1	65.4	60.1	58.8	53.3	9.8	7.1	6	50.1	41.2	40.0	32.8	12.0	8.5	1.5–1

*Seed germination low.
†Slight stunting.
‡Plants slightly stunted in one of two experiments.

Two experiments were made with subterranean clover in which varying dosages of New Improved Ceresan and Ceresan were compared. The results (Table 7) indicate that Ceresan was most effective when used at dosages of 1.5 and 0.75%, and with New Improved Ceresan some increase in stand was obtained at dosages of 0.75 and 0.375%.

TABLE 7.—*Effect of various dosages of New Improved Ceresan and Ceresan on stand of Trifolium subterraneum.*

Treatment*	Percentage dust added by weight					Difference necessary for significance at	
	1.5	0.75	0.375	0.188	Check	1% point	5% point
New Improved Ceresan	54.3†	66.9‡	64.6	62.6	54.2	11.4	8.5
Ceresan	71.5	69.9	59.0	55.5			

*Six thousand seed to treatment.
†Stunted badly.
‡One replication stunted.

DISCUSSION AND SUMMARY

Although seed to which nodule bacteria have been added cannot be treated with fungicides without killing the bacteria, it would seem from the results presented here that seed treatment of small-seeded legumes may be helpful in increasing stands. Further tests under field conditions and with various soil types are necessary before recommendations may be made.

Five fungicides were tested in the greenhouse as to their relative efficiency in controlling damping off with various species of *Lespedeza*, *Lotus*, *Medicago*, *Melilotus*, and *Trifolium*. Highly significant increases in stand were secured with certain fungicides with certain species. Others did not respond to the various treatments tried, and in some cases injury resulted. Preliminary dosage studies were made.

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NOTES

SOIL SAMPLING TUBE WITH INNER LINER

THE accompanying illustration (Fig. 1) shows the longitudinal section of a sampling tube devised by the writer for obtaining core samples of soils with a minimum of disruption. An inner liner may be placed in the tube to facilitate removal of the core without alteration of the structure, an operation which is difficult with sandy or friable soils, without some special device. Waxed wrapping paper and a synthetic pliable sheeting (DuPont's "plastacele", thickness 0.01 inch) have been used successfully. Profile samples may be kept in a transparent inner liner such as plastacele for display purposes.

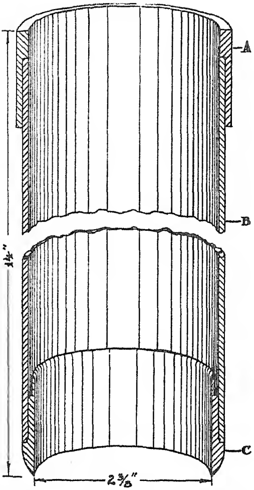

FIG. 1.—Section of sampling tube designed to obtain core samples of soil with a minimum of diruption.

In Fig. 1, B is a brass cylinder; A is a steel collar shrunk onto the cylinder to protect it when driven into the soil; and C is a specially designed bit made of hardened steel. This bit has the cutting edge bevelled on the outside as shown. There is a clearance of approximately $\frac{1}{16}$ inch between the top of the bit and the inside wall of the cylinder to receive the lower edge of the inner liner. The inner liner is not shown in the diagram. The upper edge of the bit is very slightly bevelled on the inside. The bit fits the cylinder snugly but is loose enough so that it can be removed by hand. A cylindrical wooden plunger is used to push the soil core out of the cylinder.

Credit is given Professor C. I. Gunness of the Engineering Department, Massachusetts State College, Amherst, Mass., for supervising the construction of this sampler. It is believed that the dimensions of the tube may be varied considerably from those shown in the diagram without affecting its use.—A. B. BEAUMONT, *Massachusetts State College, Amherst, Mass*

BORON DEFICIENCIES IN CONNECTICUT

IN THE Soil Science Society of America PROCEEDINGS, Volume 4, 1939, E. R. Purvis published a list of crops affected by boron deficiency in 24 states. In Connecticut, only alfalfa, celery, and rutabagas were reported as having responded to additional boron.

In further experiments on either moderately or heavily limed Merrimac sandy loam soil at the Storrs Experiment Station during 1940, mangels manifested very pronounced boron deficiency symptoms on plots where borax was not applied. Under the same conditions, spinach, lettuce, and cabbage yielded much more with than without borax, but string beans, carrots, and tomatoes showed no apparent affects from that treatment. Soybeans grew slightly larger and turnips had less corky tissue on the borax plots.

On 5 of 15 farms with cooperative experiments, alfalfa again exhibited the characteristic boron deficiency symptoms.—B. A. BROWN, *Storrs (Connecticut) Agricultural Experiment Station.*

CALAMAGROSTIS EPIGEIOS IN WISCONSIN

CALAMAGROSTIS epigeios (L.) Roth, has been grown in the grass garden of the Wisconsin Agricultural Experiment Station at Madison since 1936. F. W. Tinney obtained a few rhizomes from the U. S. Dept. of Agriculture which were later transplanted in the garden by use of a submerged barrel in a manner to prevent the spread of this aggressive grass to adjacent areas.

C. epigeios was described in 1936 by H. N. Vinall, Bureau of Plant Industry, U. S. Dept. of Agriculture. The species was obtained by the Department from Echo, Manchuria, June 21, 1923. Hansen of South Dakota had obtained some from Siberia a few years earlier. It has also been reported growing naturally in Massachusetts and Pennsylvania. The grass has been grown experimentally at various field stations of the U. S. Dept. of Agriculture and in cooperation with experiment stations in Kansas, Texas, Oregon, Nebraska, Missouri, Oklahoma, and South Dakota. This grass should not be confused with the true chee (Tshee) grass of Russia, *Stipa splendens* (*Lasigrostis splendens*), which has an entirely different habit of growth being very definitely a bunch grass without long rhizomes or stolons.

The occurrence of *C. epigeios* in Wisconsin was first noted as a plant specimen from a farm in Pierce County, Wisconsin, which had been sent to Miss Ruby U. Crouley, Seed Analyst, State Department of Agriculture, St. Paul, Minnesota, in 1939 for identification. This grass was being propagated vegetatively on this farm in an effort to revegetate a poor soil for the control of erosion and to provide summer pasturage. The land owner obtained six or seven plants in 1936 from a friend who had brought them from Russia where he had been in the employ of the Russian Government. They were transplanted in a garden and orchard where they soon took possession of a considerable area which is now being used as a nursery for continued propagation. Through vegetative plantings in rows 3 feet apart, during 1936 and 1937, the grass now covers some 10 acres

of unproductive and eroded land previously abandoned on this farm. The rows were cultivated for the first year to reduce the competition from weeds. On the better soils in the garden and orchard, the grass completely filled the space between the rows by the end of the second year. The spread was less rapid on the depleted soils of the abandoned fields. In the garden and orchard, the grass appears to compete on fairly even terms with quack grass, but it has not encroached upon a heavy bluegrass sod which borders one side of the garden.

About 2 acres of the grass established in 1937 were plowed in the spring of 1940. The soil was disked and harrowed during the summer and in August no evidence of live plants could be found. Whether or not the grass has been destroyed by cultivation can be ascertained only at a later date. The grass is utilized for pasture and appears to be quite palatable if grazed at early stages of growth. Close grazing, however, seems to be harmful if not destructive, and greatly retards its spread.

C. epigeios is also grown in a collector's garden at Menomonie, Wisconsin. Here it has been successfully eradicated by treatment with sodium chlorate. Four plants established in a gully in Green County in 1937 have spread from an area of 4 square feet to an area of approximately 400 square feet in the past 3 years.

Seed secured from four sources in Wisconsin has failed to germinate. Whether this failure of germination is due to dormancy, defective embryos, or other factors has not been ascertained. *C. epigeios* may have possibilities for erosion control and for pasturage. However, with its aggressive habits, further research is necessary to determine if its persistence is such as to make it undesirable.—F. V. BURCALOW, *Department of Agronomy, University of Wisconsin, Madison, Wis.*

AN INEXPENSIVE, PRACTICAL NURSERY HARVESTER[1]

A NEW type of nursery harvester which one man can pull and at the same time actuate the sickle with a hand lever was designed and used successfully at the Southern Great Plains Field Station, Woodward, Oklahoma. With a crew of three men harvesting is accomplished as rapidly as with five men cutting by hand. The machine was constructed in the station shop from available material but could be built elsewhere at an approximate total cost of $16.

The harvesting operation is most efficient when a three-man crew is used. One man walks backward, straddling a row, while pulling the machine with the left hand and operating the sickle lever with the right hand. The sickle is actuated by lateral reciprocal movement of the lever handle in 6-inch to 10-inch strokes. A second man walking beside the machine pushes the uncut grain so that the stalks fall into the cradle or carrier when cut. At the end of the row he picks up the bunch of grain and ties it with twine while holding the bundle between his knees. A third man alternating with the second repeats the operation on the next row. In this manner only 30 to 45 seconds are required to cut and tie a 16-foot row, compared with 2 to

[1]Contribution from Division of Cereal Crops and Diseases and Division of Dry Land Agriculture, Bureau of Plant Industry, U. S. Dept. of Agriculture.

$2\frac{1}{2}$ minutes by the hand-sickle method. Furthermore, machine harvesting is less tiring.

The machine is equally effective at any speed convenient to the operator. It operates readily on nursery rows spaced 12 inches apart. It can be turned in an 18-inch alley after removing the cradle, but in alleys not narrower than 3 feet it can be turned readily with the cradle attached.

All stems are cut at a uniform height above the ground. Few heads, even the small ones and those on short tillers, are lost in harvesting. There is little or no tendency to pull up shallow, loosely rooted plants when the straw is tough. The harvester has not been tested in badly lodged grain and it might not be satisfactory under such conditions. Possibly pickup guards would permit the lodged grain to be cut by machine.

The harvester was constructed so that it would be pulled, because pulling is easier than pushing in soft, cloddy, or trashy ground. Furthermore, if the grain is slightly lodged the operator separates it with his feet and legs as he backs along the row. The separation of rows in this manner is more positive and the heads of the lodged and tangled grain are less likely to be broken off by the operator's legs than they would be by metal dividers.

The machine weighs 46 pounds, including an 8-pound cradle or carrier. The details of construction, shown in Fig. 1, are described below.

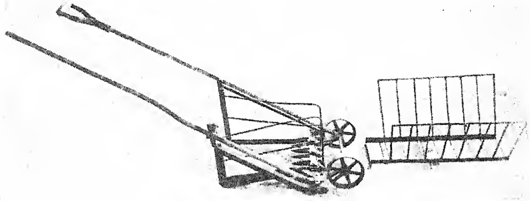

FIG. 1.—Small grain nursery harvester. (Photographed by L. F. Locke.)

The sickle consists of a $20\frac{1}{4}$-inch bar to which are attached four serrated combine sections ($2\frac{5}{8}$ x 4 inches) and roller sickle head shortened to a length of $3\frac{1}{2}$ inches and welded on the top of one end of the bar. When this head is included the sickle bar still has an overall length of $20\frac{1}{4}$ inches. Four combine guards are bolted to the cutter bar. The sickle slides a maximum distance of $5\frac{1}{4}$ inches. The wheels are $6\frac{1}{2}$ inches in diameter with rims $1\frac{7}{8}$ inches wide and the axle is a $\frac{1}{2}$-inch rod 15 inches long.

The two handles, made of $\frac{1}{2}$-inch galvanized pipe, extend back nearly $4\frac{1}{2}$ feet from the axle at such an angle that the outer ends stand about 26 inches above the ground when the machine is not in operation.

The frame was welded or bolted together largely with 1 inch x 1 inch x 1/8 inch angle iron, 3/4-inch strap iron, and 1/4 inch iron rods. The cradle was made of 3/4 inch x 3/4 inch x 1/8 inch angle iron and 1/4 inch iron rods, welded together.

Additional details of construction will be furnished interested parties upon request to the writer.—V. C. HUBBARD, *Division of Dry Land Agriculture, Woodward, Oklahoma.*

FELLOWS ELECT FOR 1940

LAURENCE FREDERICK GRABER

LAURENCE FREDERICK GRABER was born at Mineral Point, Wis., on March 5, 1887. He received the B.S. degree from the University of Wisconsin in 1910 and the M.S. degree in 1912. He was granted the Ph.D. degree by the University of Chicago in 1930. He was Professor of Agronomy at Wisconsin University from 1913 until 1940 when he was made Head of the Department of Agronomy.

He is a member of the A.A.A.S., the American Society of Agronomy, the Society of Plant Physiologists, the Ecological Society, and the Wisconsin Academy of Science.

Doctor Graber began working with alfalfa as a student at a time when the crop was being introduced to the Wisconsin farmer. Under the general direction of Professor R. A. Moore, he helped initiate the program that has placed the state near the top in acreage and production. He took an active part in developing the certified seed program in the United States in order that the alfalfa seed trade might be placed on a sound basis and adapted seed be made available for the farmers of his state.

As an extension specialist he soon realized that proper management practices would be a key factor in successful and profitable production of alfalfa. He started fundamental studies of root reserves in relation to winter survival that gradually developed into a broad program of research on crop physiology. He has published numerous papers dealing with crop management and plant physiology.

When the bluegrass in the pastures in southwestern Wisconsin was destroyed by white grubs, the fields grew up to weeds, the soil eroded badly, and productivity was greatly reduced. Doctor Graber discovered that the adult June beetle refrained from laying its eggs in pastures and meadows containing sweet clover and alfalfa. Utilizing these legumes, a system of pasture renovation and management was developed that is now generally adopted in the region and which has greatly reduced the damage caused by this insect.

FRANK WILSON PARKER

FRANK WILSON PARKER was born at Hamilton, Illinois, October 23, 1897. He and his family moved to Madisonville, Kentucky, where he was reared and received his elementary education. In 1918 he received his B.S. degree from the Alabama Polytechnic Institute and went directly to the University of Wisconsin as a National Fertilizer Association Graduate Fellow in Soils. His Ph.D. degree was conferred in 1921. From 1922 to 1927 he served as Soil Chemist at the Alabama Agricultural Experiment Station and as Acting Head of the Department of Crops and Soils from 1927 to 1929. Since 1929, he has been Agronomist for the E. I. du Pont de Nemours and Company in charge of the Ammonia Department.

Doctor Parker has been an outstanding leader in the development of physiologically neutral fertilizers. He has had an active association in the development of urea and ammonia liquors as nitrogen carriers in mixed fertilizers. His early research includes contributions to the understanding of soil moisture, the nature of soil acidity, and absorption of inorganic ions by plants. He has contributed many ideas relative to the better use of fertilizers and has been responsible for initiating much new research through du Pont fellowships.

He has been active in the affairs of the Society and served long on various fertilizer committees.

HAROLD RYLAND SMALLEY

HAROLD RYLAND SMALLEY was born on a farm in Madison County, Indiana, May 30, 1887. He received his B.S. degree from Purdue University in 1911 and the M.S. degree in 1913. He is a member of the American Society of Agronomy, the Soil Science Society of America and the American Chemical Society.

From 1911 to 1913, as Assistant Chemist with the Purdue University Agricultural Experiment Station and working with G. B. Abbott and S. D. Conner, he made valuable contributions in pioneer studies on aluminum toxicity in acid soils. From 1913 to 1915, and from 1916 to 1920, he served in the Purdue University Extension Service, chiefly in county agent work. From 1915 to 1916, he was Assistant Agrostologist and Farm Management Investigator, U. S. Dept. of Agriculture.

His chief agronomic service has been with the Soil Improvement Committee of the National Fertilizer Association. First as Regional Agronomist, 1920–24, then Regional Director, 1924–29, and since 1929 as Director of Soil Improvement Work, he has risen to a position of national leadership in crystallizing the

results of agronomic research as improved soil management practices of widespread economic benefit.

In the above capacity he has organized many working conferences between institutional agronomists and the fertilizer industry. He has instituted valuable surveys of soil management practices and of the consumption of fertilizers of various grades. The work of the various agricultural experiment stations pertaining to fertilizers and methods of fertilizer application have been digested and given wide publicity under his leadership.

As a member of the Fertilizer Committee of the Society during the past several years, he has served as Secretary of its proceedings and rendered valuable assistance to the work of its various subcommittees, especially with respect to publication of the work of the National Joint Committee on Fertilizer Application.

PAUL CHRISTOPH MANGELSDORF

Paul Christoph Mangelsdorf was born at Atchison, Kans., July 20, 1899. He attended Kansas State College where he received the B.S. degree in 1921. Harvard University granted him the M.S. degree in 1923 and the Sc.D. degree in 1925. He served as Assistant Geneticist at the Connecticut Experiment Station from 1921 to 1927, where he made numerous contributions to genetics, especially of maize.

He became Agronomist in Charge of Corn and Small Grain Investigations at the Texas Agricultural Experiment Station where, in addition to producing new varieties of sweet corn adapted to the Southwest, he continued his studies of the genetics of maize and its relatives. New disease-resistant varieties of wheat, oats, and barley also have been produced under his general direction. He was the first to hybridize maize and its remote wild relative, gama grass (Tripsacum), and from this and like hybrids he developed his theory of the origin of maize, which was published under the title "The Origin of Indian Corn and its Relatives" by the Texas Agricultural Experiment Station.

In 1936 he was made Vice Director of the Texas Experiment Station, a position he held until he assumed his present one of Professor of Botany and Assistant Director of the Botanical Museum of Harvard University.

Doctor Mangelsdorf is a member of the A.A.A.S., the Society of Naturalists, the Genetics Society, the Genetic Association, the American Society of Agronomy, the Botanical Society, and the Texas Academy of Science.

AGRONOMIC AFFAIRS

STUDENT SECTION ESSAY CONTEST FOR 1941

THE Committee on Student Sections of the American Society of Agronomy presents the following regulations governing the essay contest for 1941:

The first three winners receive expense money to enable them to attend the International Grain and Hay Show in Chicago. The total allotment for the three will not exceed $150.00. The amounts granted will vary with the distance the winners are from Chicago. For example, if a Wisconsin student won first and an Oregon student second, it would be desirable to grant a larger amount to the Oregon student, as his expenses would be greater. The committee reserves the right to adjust this as conditions warrant. In addition, the three high men will receive appropriate medals and a year's subscription to the JOURNAL of the American Society of Agronomy. The winners of the fourth, fifth, sixth, and seventh places will receive cash awards of $20, $15, $10, and $5, respectively.

All essays must be prepared by undergraduate students. Students graduating during the course of the 1940–41 school year or those graduating during the summer school of 1941 are eligible, providing their papers are submitted before graduation. A certification of eligibility to qualify as an undergraduate, signed by the Dean of the College, must accompany each paper.

Papers should be typed, double spaced and not less than 3,000 or more than 3,500 words in length. *Abstracts of not more than 500 words must accompany each paper.* Abstracts should be prepared carefully as it is planned to publish the best. Failure to submit an abstract will disqualify the paper. All papers and abstracts are to be submitted in duplicate and if it is desired that the essay be returned, postage should be enclosed.

The title for the essay shall be "The Role of Legumes in Agriculture". The subject may be treated for any section or all sections of the United States and from any angle.

The committee suggests that where several papers are entered from a given institution, the local representatives of the Society shall review the essays and submit only the best articles. This will save work for the committee and reduce mailing expenses. Usually not more than five papers should be submitted from one institution for final review by the committee. The winners of the contest will be announced at the meeting of the American Society of Agronomy in the fall of 1941, and the results published in the December issue of the JOURNAL.

Essays must be in the hands of the Chairman of the Committee, H. K. Wilson, University Farm, St. Paul, Minnesota, not later than August 1, 1941.

THE SOIL TEMPERATURE CONFERENCE

A HASTILY organized soil temperature conference held at the Drake Hotel in Chicago on December 5 was attended by representatives of the Soil Conservation Service, the U. S. regional laboratories, several of the state experiment stations, the canning industry, and equipment manufacturers. An informal discussion was held on methods of obtaining and interpreting soil and air temperatures with respect to plant growth and soil properties.

It is proposed to schedule another such conference at the time of the next meeting of the Soil Science Society of America which will be held in Washington, D. C., in November, 1941. It is hoped that by integrating this conference in the program of the Soil Science Society meetings, a larger number of interested persons will be able to participate in the discussions. For further information about the proposed soil temperature conference, write to Dr. Alfred Smith, Division of Soil Technology, University of California, Davis, California.

NEWS ITEMS

DR. O. W. WILLCOX, consulting agrobiologist, 197 Union St., Ridgewood, N. J., has laid before the presidents and deans of the agricultural colleges and directors of the experiment stations a memorandum on "The Education of an Agrobiologist; an address to the directing heads of agricultural instruction and research in the United States". A copy of this address will be mailed to any reader of the JOURNAL who requests it.

PROFESSOR R. A. FISHER, Sc.D., F.R.S., Galton Professor, University College, University of London, has accepted an offer to be a Visiting Professor of Experimental-Statistics at North Carolina State College during the summer session June 16 to July 25, 1941. Professor Gertrude M. Cox, head of the newly established department of Experimental-Statistics, also has invited several other leaders in various fields of applied statistics to come to the College this summer and assist in conducting special courses and conferences. These will be related to statistics and its associated fields and will be open to persons who may wish to attend all or a part of the summer session.

DOCTOR RICHARD BRADFIELD of Cornell University was elected Chairman of Section O (Agriculture) of the American Association for the Advancement of Science at the Philadelphia meeting of the Association last month. Dr. M. F. Morgan of the Connecticut Agricultural Experiment Station at New Haven was elected Secretary of the Section and Dr. Firman E. Bear of the New Jersey Experiment Station at New Brunswick was elected a member of the Sectional Committee.

THE THOUSAND DOLLAR prize of the American Association for the Advancement of Science, given annually for the past 18 years to the author "of some notable contribution to science presented at the meeting", was awarded at the Philadelphia meeting to Dr. D. R. Hoagland, Head of the Division of Plant Nutrition, University of California, and Dr. D. I. Arnon, of the same Division, for their paper entitled "Availability of Nutrients with Special Reference to Physiological Aspects".

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IRON STARVATION AS AFFECTED BY OVER-PHOSPHATING AND SULFUR TREATMENT ON HOUSTON AND SUMTER CLAY SOILS[1]

W. V. CHANDLER AND GEORGE D. SCARSETH[2]

IRON starvation limits the growth of certain plants, *viz.*, lespedeza, crotalaria, peanuts, sweet potatoes, and morning-glory vines, on the Sumter clays which are high in free $CaCO_3$. Spraying the plants with a solution containing $FeSO_4$(0.03%), $MnSO_4$ (0.01%), and $MgSO_4$ (0.02%) has corrected this condition, but this treatment is impractical and inconvenient; solutions of $FeSO_4$ oxidize rapidly, spraying consumes much labor and needs to be repeated frequently, and the soil condition is not altered. A better solution to this problem might be that of releasing iron in the soil. Sulfur will neutralize the $CaCO_3$ by the formation of sulfuric acid and the resulting solvent action may tend to increase the availability of iron to plants. The work reported herein on Sumter clay was designed to study this problem.

It has been noted that the crop yields have been less on the slightly alkaline Bell and Houston clays where very heavy annual applications of superphosphate were made than where smaller applications prevailed. It is possible that the large amounts of soluble phosphates have precipitated enough of the soluble iron to produce an iron starvation condition for the susceptible plants. The work herein reported on the Houston clay is intended to give some facts about the possibility of iron starvation as caused by overphosphating.

REVIEW OF LITERATURE

Very little work has been published concerning the problem of chlorosis or iron starvation caused by applications of phosphates which render the iron unavailable for plant assimilation.

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication July 8, 1940.

[2]Formerly Graduate Assistant and Associate Soil Chemist, respectively, Alabama Agricultural Experiment Station. Senior author, graduate student Ohio State University, Columbus, Ohio, since July 1940, and junior author Soil Chemist, Purdue University, Agricultural Experiment Station, Lafayette, Ind., since February 1938.

Gile and Carrero (1)[3] have demonstrated that applications of lime to soils induced chlorosis. Analyses of the plants revealed that an iron deficiency was one of the causes of the chlorosis with possibly an excess of lime as a contributory cause. Scholz (4) has also shown that unless iron was added to sand cultures along with the lime a chlorotic condition was produced. Myers and Johnson (2) attributed the chlorosis of western Kansas plants to iron deficiency.

Olsen (3) reported that plants grown in solutions with pH values above 7 were chlorotic due to iron deficiency. This trouble was overcome if the iron was present as the citrate, humate, or other organic salt. Sideris and Krauss (5) found that applications of phosphate to soils produced chlorosis in plants only on soils having pH values above 6. This was attributed to the fixation of the soluble iron as insoluble iron phosphates. Wann (6) suggested two possible control measures for chlorosis caused by iron deficiency, one, spraying the plants with $FeSO_4$, or by injections of various iron salts into the plants; two, soil treatments with manures, ammonium sulfate, or elemental sulfur.

EXPERIMENTAL

For the purposes of these investigations, two sets of pots were provided, each set consisting of 64 1-gallon earthen ware jars. To one set 4 kilograms per pot of Houston clay were added and to the other set a similar amount of Sumter clay. Each set was then divided into two series, one (32 pots) for peanuts, the other (32 pots) for alfalfa. Elemental sulfur and superphosphate, at the various rates per pot shown in Tables 1 and 3, were thoroughly mixed with the soils. The soils were brought to optimum moisture content (15 to 25%) with rainwater and maintained within that range of moisture content for 1 month. At the end of 2, 5, 8, 13, 18, and 27 days, samples were taken for determinations of pH and moisture content and also for phosphorus, iron, and sulfates soluble in carbonated water.

One month after the original phosphate and sulfur treatments, peanuts and alfalfa were planted in accordance with the arrangements shown in Tables 1 and 3. These crops were fertilized with $NaNO_3$ and KCl at planting time and allowed to grow for 3 months. At the end of this period, just before harvest, numbers were recorded for the relative chlorosis.

The yields were determined, and the plants in pots 1 to 14 and 27 to 32, inclusive, were analyzed for phosphorus and iron by standard methods. Three crops of the same species were grown successively on each series of pots following the first phosphate and sulfur applications, after which these applications were repeated and similar laboratory determinations made on the soils as before, after the same intervals of time. Each series of pots was then again cropped to three successive harvests of the same species of plants and data obtained as before.

RESULTS AND DISCUSSION

The results of the pH determinations of the soils following the first sulfur and phosphate treatment are presented in Fig. 1. It is readily seen that the addition of as much as 4 tons of elemental sulfur per acre to Sumter clay had but slight effect on its pH value. The slight reduction noted occurred between 5 and 13 days after addition of the sulfur. It can be seen that in the Houston clay there was no significant reduction in the pH value for 5 days, but during the interval between the fifth and eighth days there was a rapid decrease.

[3]Reference by numbers in parenthesis is to "Literature Cited", p. 104.

There was a gradual and general decrease in pH throughout the 27-day period. The decrease in pH values was greater with the heavier sulfur applications.

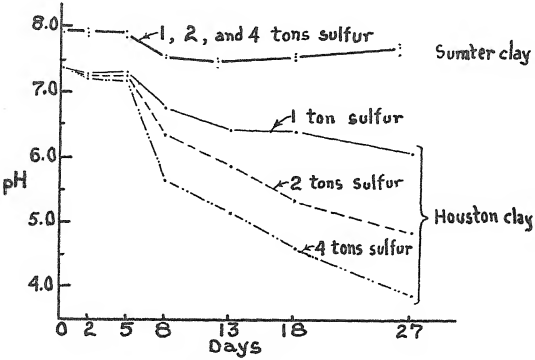


FIG. 1.—Influence of the first sulfur treatment on the pH of Sumter and Houston clays.

The data in Fig. 2 show the reduction in pH values of the clays following the second sulfur and phosphate treatments. It is clearly shown that the second treatment again had only slight effect on the pH values of the Sumter clay. The second treatment on the Houston clay affected the pH values considerably. The most rapid reduction in pH values again occurred between the fifth and eighth days after the repeated treatment. The pots receiving the 4-ton rate of application of sulfur reached a low pH of 3.08.

Figs. 3 and 4 show the rate of sulfofication in each soil following the first and second sulfur treatment, respectively. It is readily seen that the two soils were similar with respect to the 1- and 2-ton rates of sulfur, but were different when 4 tons of sulfur were applied. More sulfates were produced in the Sumter clay than in the Houston, although considerable sulfate was produced in the latter. The most rapid rate of oxidation occurred in the Sumter clay receiving 4 tons sulfur; whereas, the low pH values produced in the Houston clay following the second application retarded the rate of oxidation. This was particularly noticeable with the 4-ton application.

In tests of both soils, soluble iron was found to be present only in the Houston soil which received the 4-ton rate of sulfur without phosphate. A maximum of 4.3 pounds of soluble Fe_2O_3 per acre occurred following the second treatment with 4 tons of sulfur per acre.

The amount of soluble phosphorus present increased with increasing phosphate applications, but showed no correlation with the sulfur

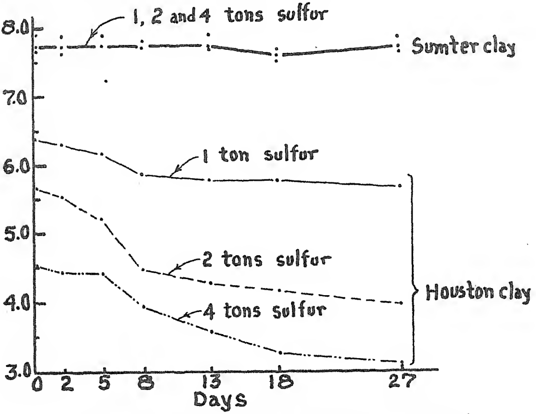


FIG. 2.—Influence of the second sulfur treatment on the pH of Sumter and Houston clays.

treatment in the Sumter or Houston clays. There was no appreciable amount of phosphorus soluble in water saturated with CO_2 in either clay following the first treatment; however, 2 days after the second treatment there was a maximum of 75 pounds of soluble P_2O_5 per acre in the Sumter clay, but this amount decreased rapidly with time.

Table 1 presents a summary of the average pH values of the soil, and yields, relative chlorosis, and Fe_2O_3 and P_2O_5 contents of the

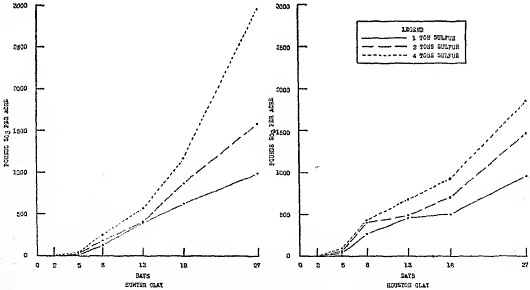
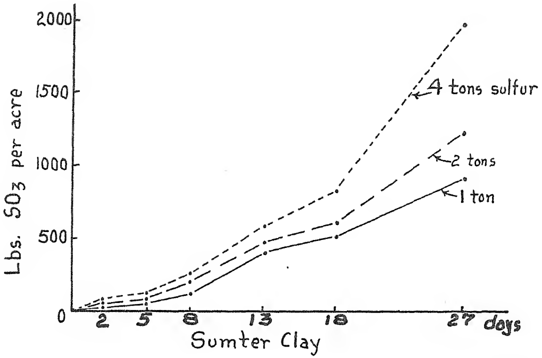


FIG. 3.—The rate of sulfofication in Sumter and Houston clays following first application of sulfur and phosphate.



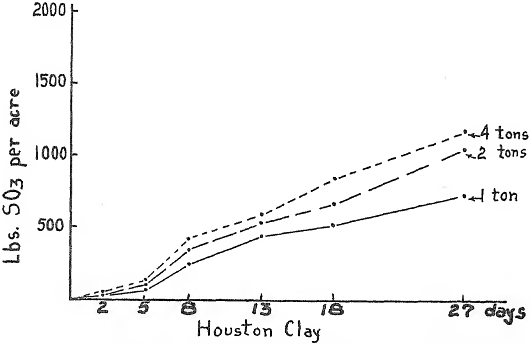


FIG. 4.—The rate of sulfofication in Sumter and Houston clays following the second application of sulfur and phosphate.

three crops of peanuts and alfalfa grown on Houston clay following the first treatments. Table 2 gives the same data for the second successive three crops. The yields, relative chlorosis, and Fe_2O_3 and P_2O_5 contents of the plants grown following each treatment with sulfur and phosphate varied considerably. In general, following the second treatment, the yields decreased and the relative chlorosis slightly increased. The pH values were lower in the soils following the second sulfur treatments.

TABLE 1.—*Treatment and pH of soils and average of three successive crops in duplicate of yields, relative chlorosis, and Fe_2O_3 and P_2O_5 contents of peanuts and alfalfa grown on Houston clay following the first application of various amounts of phosphate and sulfur.*

Pots of each series	Fertilizer treatment†	pH of soil‡	Peanuts						Alfalfa*				
			Yield, dry weight in grams	Relative chlorosis§	Fe_2O_3		P_2O_5		Yield, dry weight in grams	Fe_2O_3		P_2O_5	
					Mgms per 100 grams dry material	Relative amounts	Mgms per 100 grams dry material	Relative amounts		Mgms per 100 grams dry material	Relative amounts	Mgms per 100 grams dry material	Relative amounts
1–2	0 0	7.8	8.5	1.0	37.2	100	343	100	2.17	40.9	100	488	100
3–4	P 0	7.9	10.8	1.0	35.8	96	384	112	3.84	36.6	90	646	132
5–6	4P 0	7.6	11.1	1.0	32.6	88	425	124	4.73	34.8	85	837	171
7–8	8P 0	7.5	13.9	1.5	31.8	85	467	136	4.85	37.5	92	1,050	215
9–10	0 S	6.6	9.0	1.5	41.0	111	375	109	2.75	48.3	118	521	107
11–12	0 2S	5.4	12.1	1.5	40.5	109	459	134	3.84	51.1	125	648	133
13–14	0 4S	4.2	9.6	1.5	47.5	128	570	166	1.58	54.3	133	654	134
15–16	P S	6.2	11.8	1.0	—	—	—	—	4.19	—	—	—	—
17–18	P 2S	5.2	11.9	1.5	—	—	—	—	4.99	—	—	—	—
19–20	P 4S	4.1	14.5	1.5	—	—	—	—	1.30	—	—	—	—
21–22	4P S	6.2	12.8	1.5	—	—	—	—	4.42	—	—	—	—
25–26	4P 4S	4.1	11.6	2.0	—	—	—	—	2.47	—	—	—	—
27–28	8P S	6.1	15.8	1.5	35.7	96	615	179	5.36	47.7	117	913	187
29–30	8P 2S	5.4	14.1	1.0	36.6	99	693	202	6.19	37.3	91	852	175
31–32	8P 4S	4.1	13.1	1.5	33.6	90	603	176	2.76	35.8	90	463	95

*No chlorosis was observed in the alfalfa.

†Each pot received $NaNO_3$ and KCl at rate of 500 pounds and 100 pounds per acre, respectively. P = 800 pounds of 16% superphosphate per acre and S = 2,000 pounds elemental sulfur per acre. Minor elements except iron were added at first date of planting.

‡Average pH value of duplicate pots at date of each planting. The greatest range of variation was ±0.12 pH.

§1 = no chlorosis; 2 = slight chlorosis; 3 = medium chlorosis; 4 = extreme chlorosis; 5 = dying from extreme chlorosis.

TABLE 2.—*Treatment and pH of soils and average of three successive crops in duplicate of yields, relative chlorosis, and Fe_2O_3 and P_2O_5 contents of peanuts and alfalfa grown on Houston clay following second application of various amounts of phosphate and sulfur.*

Pots of each series	Fertilizer treatment‡		pH of soil§	Peanuts*						Alfalfa†				
				Yield, dry weight in grams	Relative chlorosis¶	Fe_2O_3		P_2O_5		Yield, dry weight in grams	Fe_2O_3		P_2O_5	
						Mgms per 100 grams dry material	Relative amounts	Mgms per 100 grams dry material	Relative amounts		Mgms per 100 grams dry material	Relative amounts	Mgms per 100 grams dry material	Relative amounts
1–2	0	0	8.0	6.5	1.0	29.1	100	266	100	0.70	22.6	100	552	100
3–4	P	0	7.9	8.0	1.5	35.1	120	385	150	2.20	17.8	76	691	125
5–6	4P	0	7.7	9.5	2.0	30.6	105	499	195	2.47	22.3	99	706	128
7–8	8P	0	7.5	10.3	2.5	29.8	102	527	205	2.73	22.3	99	859	156
9–10	0	S	5.7	8.4	1.5	38.5	132	300	117	1.40	28.4	126	608	110
11–12	0	2S	4.4	7.2	1.5	35.2	121	254	99	1.00	23.4	104	580	105
13–14	0	4S	3.3	2.9	1.0	39.2	135	237	93	0	—	—	—	—
15–16	P	S	5.4	10.0	2.0	—	—	—	—	3.06	—	—	—	—
17–18	P	2S	4.4	8.8	1.5	—	—	—	—	1.21	—	—	—	—
19–20	P	4S	3.2	2.8	1.0	—	—	—	—	0	—	—	—	—
21–22	4P	S	5.4	11.1	2.0	—	—	—	—	3.30	—	—	—	—
25–26	4P	4S	3.2	3.5	1.0	—	—	—	—	0	—	—	—	—
27–28	8P	S	5.3	11.9	2.5	30.7	105	589	230	3.62	17.0	75	979	177
29–30	8P	2S	4.3	11.1	2.5	27.8	95	732	285	1.45	30.3	134	884	160
31–32	8P	4S	3.2	4.1	1.5	35.0	120	562	219	0	—	—	—	—

*Average of three crops including five pots.
†One crop only. The pots were planted to peanuts the last two crops. No chlorosis was observed in the alfalfa.
‡Each pot received $NaNO_3$ and KCl at rate of 500 pounds and 100 pounds per acre, respectively. P = 800 pounds of 16% superphosphate per acre and S = 2,000 pounds elemental sulfur per acre. Minor elements except iron were added at first date of planting.
§Average pH values of duplicate pots at date of each planting. The greatest range of variation was ±0.15 pH.
¶1 = no chlorosis; 2 = slight chlorosis; 3 = medium chlorosis; 4 = extreme chlorosis; 5 = dying from extreme chlorosis.

Tables 3 and 4 summarize the average pH values of the soil, the yields, relative chlorosis, and Fe_2O_3 and P_2O_5 contents of peanuts and alfalfa grown on Sumter clay following the first and second sulfur and phosphate treatments. Although the yields and relative chlorosis were lower following the second than the first treatment, they were slightly increased by the treatments and the analyses of the plants varied in each direction from the controls. The degree of chlorosis of the peanuts followed no definite correlation with either their Fe_2O_3 and P_2O_5 contents or their ratios.

The data (Fig. 1) show that 4 tons of sulfur per acre had only slight effect on the pH of Sumter clay. This was also found to be true with the second 4-ton application (Fig. 2). Sumter clay is a soil derived from rotten limestone of the Selma chalk formation and contains a large excess of free $CaCO_3$. The sulfuric acid produced by oxidation of 8 tons of sulfur by the organisms of the soil was not sufficient to neutralize the lime present and reduce the pH of this soil.

The pH values of the Houston clay were reduced considerably by even the lowest sulfur application (Fig. 1) since there was sufficient acid produced to more than neutralize the free lime. The 4-ton application had a tremendous effect on the pH of Houston clay.

The curves in Fig. 3 show that the sulfur-oxidizing bacteria were very active throughout the entire 27-day period. Even though the pH of the Sumter clay was not changed appreciably by the addition of sulfur, the quantity of sulfates in the soil gradually increased showing that the sulfur was continually being oxidized. The rate of sulfur oxidization was considerably greater after the first than after the second sulfur and phosphate treatment (Figs. 3 and 4).

The crop yields following the second sulfur and phosphate treatment were lower than after the first (Tables 2 and 4). This may have been due to reductions in amounts of available iron for the plants where phosphates alone, or where extremely high phosphate applications with sulfur, were made. The extreme acidities produced in some of the pots would also result in a reduction in legume yields, especially those of alfalfa. There were four failures of alfalfa on the Houston clay following the second sulfur treatment, probably due to increased hydrogen-ion concentration, and for this reason the pots were planted to peanuts for the last two crops.

No chlorosis was observed in any of the crops of alfalfa on either soil, but peanuts grown on Houston clay showed some symptoms of iron deficiency. There was little variation in chlorosis in the first three crops due to the various treatments, but there was in the second three. When extremely high rates of phosphate were used, the plants were more chlorotic. The sulfur applications partially corrected this condition.

Phosphate applications alone on the Houston clay caused a reduction in the percentage iron content of the first three crops of peanuts and alfalfa as compared with that of the control pots (Table 1). A decrease in percentage of iron in plants fertilized with 6,400 pounds of superphosphate per acre and sulfur was noted. On the contrary, more iron was removed by those crops than by the controls since the increases in yields were more than compensated for by the dilution of

TABLE 3.—*Treatment and pH of soil and average of three successive crops in duplicate of yields, relative chlorosis, and Fe_2O_3 and P_2O_5 contents of peanuts and alfalfa grown on Sumter clay following the first application of various amounts of phosphate and sulfur.*

Pots of each series	Fertilizer treatment†		pH of soil‡	Peanuts						Alfalfa*				
				Yield, dry weight in grams	Relative chlorosis§	Fe_2O_3		P_2O_5		Yield, dry weight in grams	Fe_2O_3		P_2O_5	
						Mgms per 100 grams dry material	Relative amounts	Mgms per 100 grams dry material	Relative amounts		Mgms per 100 grams dry material	Relative amounts	Mgms per 100 grams dry material	Relative amounts
1–2	0	0	8.0	8.0	2.0	38.7	100	429	100	2.19	23.5	100	458	100
3–4	P	0	8.1	8.0	3.5	44.9	116	456	106	3.38	26.6	113	559	122
5–6	4P	0	8.0	8.0	3.5	65.1	168	599	140	3.80	23.8	101	670	146
7–8	8P	0	7.8	9.4	4.0	58.0	150	618	144	4.07	23.0	98	783	171
9–10	0	S	7.8	8.1	3.5	42.6	110	461	107	3.28	31.1	132	531	116
11–12	0	2S	7.7	9.4	3.0	51.9	134	449	105	3.41	27.5	117	532	116
13–14	0	4S	7.6	9.3	2.5	38.6	100	464	108	3.42	30.1	128	571	125
15–16	P	S	7.8	9.3	3.5	—	—	—	—	4.21	—	—	—	—
17–18	P	2S	7.7	9.9	4.0	—	—	—	—	3.95	—	—	—	—
19–20	P	4S	7.6	8.9	3.5	—	—	—	—	4.15	—	—	—	—
21–22	4P	S	7.7	9.0	3.5	—	—	—	—	3.69	—	—	—	—
23–24	4P	2S	7.7	9.8	3.0	—	—	—	—	4.15	—	—	—	—
25–26	4P	4S	7.6	9.9	2.0	—	—	—	—	3.69	—	—	—	—
27–28	8P	S	7.8	9.6	3.5	42.8	111	614	143	3.80	22.9	97	815	178
29–30	8P	2S	7.6	10.4	2.5	40.2	104	562	131	3.82	22.2	94	785	171
31–32	8P	4S	7.5	10.5	2.5	39.5	102	659	154	4.55	26.3	112	748	163

*No chlorosis was observed in the alfalfa.

†Each pot received $NaNO_3$ and KCl at rate of 500 pounds and 100 pounds per acre, respectively. P = 800 pounds of 16% superphosphate per acre and S = 2,000 pounds elemental sulfur per acre. Minor elements except iron were added at first date of planting.

‡Average pH value of duplicate pots at date of each planting. The greatest range of variation was ±0.19 pH.

§1 = no chlorosis; 2 = slight chlorosis; 3 = medium chlorosis; 4 = extreme chlorosis; 5 = dying from extreme chlorosis.

TABLE 4.—*Treatment and pH of soil and average of three successive crops in duplicate of yields, relative chlorosis, and Fe_2O_3 and P_2O_5 contents of peanuts and alfalfa grown on Sumter clay following second application of various amounts of phosphate and sulfur.*

Pots of each series	Fertilizer treatment‡		pH of soil§	Peanuts*						Alfalfa†				
				Yield, dry weight in grams	Relative chlorosis¶	Fe_2O_3		P_2O_5		Yield, dry weight in grams	Fe_2O_3		P_2O_5	
						Mgms per 100 grams dry material	Relative amounts	Mgms per 100 grams dry material	Relative amounts		Mgms per 100 grams dry material	Relative amounts	Mgms per 100 grams dry material	Relative amounts
1–2	0	0	8.1	5.9	2.0	33.8	100	289	100	1.59	11.7	100	399	100
3–4	P	0	8.1	6.1	3.0	48.7	144	460	194	2.19	14.9	127	541	137
5–6	4P	0	8.0	6.3	4.0	44.8	132	535	185	2.25	12.1	104	746	187
7–8	8P	0	7.9	5.7	4.5	45.0	133	587	203	1.50	9.4	80	731	183
9–10	0	S	7.8	5.8	2.5	42.8	126	374	130	1.62	9.6	82	457	114
11–12	0	2S	7.8	6.4	2.5	41.8	124	290	101	1.45	10.0	85	487	122
13–14	0	4S	7.7	6.1	2.0	35.4	105	304	105	1.27	11.3	97	543	136
15–16	P	S	7.8	7.0	3.0	—	—	—	—	1.95	—	—	—	—
17–18	P	2S	7.7	7.3	2.5	—	—	—	—	1.74	—	—	—	—
19–20	P	4S	7.7	7.0	2.5	—	—	—	—	1.97	—	—	—	—
21–22	4P	S	7.7	6.6	3.0	—	—	—	—	2.12	—	—	—	—
23–24	4P	2S	7.7	7.0	2.5	—	—	—	—	2.05	—	—	—	—
25–26	4P	4S	7.7	7.4	2.0	—	—	—	—	1.70	—	—	—	—
27–28	8P	S	7.7	7.4	3.5	31.9	94	508	176	1.81	7.1	61	735	184
29–30	8P	2S	7.7	7.4	2.5	31.4	93	476	165	1.50	12.0	103	757	190
31–32	8P	4S	7.7	7.4	2.0	27.9	83	494	171	1.30	9.8	83	805	202

*Average of three crops including five pots.

†One crop only. The pots were planted to peanuts the last two crops. No chlorosis was observed in the alfalfa.

‡Each pot received $NaNO_3$ and KCl at rate of 500 pounds and 100 pounds per acre, respectively. P = 800 pounds of 16% superphosphate per acre and S = 2,000 pounds elemental sulfur per acre. Minor elements except iron were added at first date of planting.

§Average pH values of duplicate pots at date of each planting. The greatest range of variation was ±0.21 pH.

¶1 = no chlorosis; 2 = slight chlorosis; 3 = medium chlorosis; 4 = extreme chlorosis; 5 = dying from extreme chlorosis.

their iron content. The use of sulfur alone caused an increase in iron assimilation above that of the controls. The analyses of the three crops following the second treatments did not show the same variations in iron content; however, the results of analyses should not be considered too indicative of the chlorotic conditions of plants. The phosphorus content of the plants was increased above that of the checks following practically all of the phosphate treatments.

Considerable chlorosis was prevalent in the peanuts on the Sumter clay (Tables 3 and 4). It can be seen from the results that practically all the plants were less chlorotic after the second treatment than they were following the first. In all instances plants grown in the pots receiving only phosphates were more chlorotic than the controls. Applications of sulfur along with the phosphate partially corrected the chlorotic condition, the larger the sulfur application the greater the corrective effect.

The chlorotic condition was attributed to iron starvation. This belief was substantiated because minor elements except iron were applied to the pots at the date of planting the first and fourth crops, and furthermore, spraying of the plants (plants in pots not to be analyzed) with $FeSO_4$ (0.03%) proved effective in correcting the chlorotic condition.

SUMMARY

Houston (pH 7.78) and Sumter (highly calcareous) clays were placed separately in 1-gallon pots and treated with various amounts of superphosphate and elemental sulfur. There were two series of 32 pots per series for each soil. The soils were wetted and maintained at optimum moisture content for a period of 1 month after which one series of each soil was planted to peanuts and the other to alfalfa. At the end of 2, 5, 13, 18, and 27 days following the treatment, samples were taken and determinations made for moisture content, pH value, and carbonated water-soluble phosphate, iron, and sulfate. Records were made of the relative degree of chlorosis of the plants after 3 months' growth when the plants were harvested and their dry weights determined. The plants were analyzed for phosphorus and iron. Three successive crops were grown and then the phosphate and sulfur treatments were repeated. Samples of the soils were again taken and three more successive crops were grown on each soil and analyzed.

The application of phosphate to the Houston and Sumter clays produced iron chlorosis in peanuts on both soils, but more severely on the Sumter clay, while applications of sulfur to both soils reduced the chlorotic condition of the peanuts, with the treatment being more effective on the Sumter than on the Houston soil. Symptoms of chlorosis were not evident with the alfalfa following any of the phosphate treatments; however, the iron content of the alfalfa was decreased with the addition of phosphate alone on Houston clay.

Sulfur applied to both soils was readily oxidized to sulfates, the rate increasing with increasing applications of both sulfur and phosphate. In the early stages the rate of sulfofication was slightly more rapid in the Houston clay, but in the later stages this was reversed

with the high applications due to the intense acidity developed in the Houston clay. The pH value of the Sumter clay was not appreciably affected by 8 tons of elemental sulfur due to the highly calcareous nature of this soil, while that of the Houston clay was lowered by even 1 ton, and the larger the application the greater was the reduction.

The results of chemical analyses of the plants grown on either soil revealed no definite correlation between the relative chlorosis and either the total amounts of Fe_2O_3 and P_2O_5 removed by the crops, the percentage contents of these, or the ratio of Fe_2O_3 to P_2O_5 in the plants. It appears that at least a considerable portion of the iron in a plant may be assimilated in such a manner that it does not prevent a chlorotic condition of the plant.

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FERTILIZER PLACEMENT UNDER IRRIGATION IN WASHINGTON[1]

C. EMIL NELSON AND L. C. WHEETING[2]

STUDIES of the relative value of localized and broadcast methods of fertilizer application, particularly with row crops, have assumed increasing importance within the last 10 years. Experimental data (4, 5, 6),[3] reported from the eastern part of the United States under summer rainfall conditions, have shown that localized applications are generally more efficient than broadcast applications, but that certain localized placements are definitely unsatisfactory.

Farmers in the Yakima Valley of Washington who have tried localized fertilizer applications on irrigated crops have often obtained serious decreases in stand and yield due to improper placement. Consequently, this study was undertaken to determine the best methods of application with row crops and to indicate the value of proper placement when irrigation water might move the greater portion of the fertilizer.

PLAN OF EXPERIMENT

The experimental work was divided into two parts. The first part dealt with the application of nitrogen, phosphorus, and potassium fertilizers in a localized band in the soil, followed by 12- and 24-hour applications of irrigation water with subsequent sampling, analysis, and determination of the fertilizer movement in the soil.

The second part dealt with the localized application of various amounts of nitrogen and phosphorus fertilizers at different distances to the side, under, and over the seed of corn and beans. Potassium was not included because previous experimental data (7, 9) obtained on this soil type have shown little or no significant crop response to this element with either corn or legumes.

FERTILIZER MOVEMENT UNDER IRRIGATION

APPLICATION AND IRRIGATION

A uniformly sloping field of Sagemoor fine sandy loam was selected for this study. During the previous year the field was fallow and received no irrigation. Prior to that time the field had been in pasture rotation experiments and had not been fertilized.

A fertilizer mixture containing sodium nitrate (15.5% N), treble superphosphate (42% P_2O_5), and muriate of potash (50% K_2O) was placed in a band 1 rod

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[3]Figures in parenthesis refer to "Literature Cited", p. 114.

long and 2 inches wide. It was located 2 inches deep, 8 inches away, and parallel to an irrigation ditch. About 278 grams of sodium nitrate, 130 grams of treble superphosphate, and 104 grams of muriate of potash were used in order that a portion of the application would remain undissolved after being irrigated.

Three weeks prior to the beginning of the experiment, the field was irrigated in regular irrigation ditches 3 feet apart so that the subsoil would contain an amount of water comparable to normal field conditions and in order that the water applied in the experiment would be able to make a quicker moisture contact and move more rapidly to lower levels (3).

A 12-hour irrigation was applied in the ditch by ordinary field methods after the fertilizer band was placed. This irrigation amounted approximately to 4-acre inches of water (3). Two weeks later, a 24-hour irrigation, amounting to approximately 8-acre inches of water, was applied in the same ditch.

SAMPLING

Twenty-four hours after each irrigation, when the moisture had become distributed, a 5-foot trench was dug at right angles to the fertilizer band and irrigation ditch. The cross-trench dug after the second irrigation was 8 feet further down the ditch from the first trench, the latter having been filled and a flume put across it.

The face of each trench was smoothed off with a spade, and small pegs were driven into the soil at measured distances. Then the samples were taken with a soil tube, going hortizontally into the face of the trench. The soil was placed in soil cans and later dried and sieved. Soil moisture determinations were made the day of sampling.

ANALYSIS

The presence of the applied nutrients was determined by making water extractions for nitrates and potassium and fifth normal nitric acid extractions for phosphorus, using a ratio of 1 part of soil to 5 parts of water or solution. The nitrates in solution were determined by the A. O. A. C. (1) phenoldisulfonic acid method, phosphorus by the A.O.A.C. (1) volumetric method, and potassium according to the method of Volk and Truog (8).

EXPERIMENTAL RESULTS

WATER PENETRATION

With 12 hours of irrigation as shown in Fig. 1, the lateral movement of water was 10 to 12 inches from the fertilizer band on the surface to over 18 and 30 inches at the 18-inch level. Downward penetration was to the fifth foot. A similar pattern was followed when irrigated 24 additional hours except the lateral movement was increased approximately 12 inches on both sides.

NITRATES

The nitrates subjected to 12 hours of irrigation moved 8 inches horizontally from the band as shown in Fig. 1 and Table 1. The downward movement was slight, a small amount penetrating to the 4-inch level 14 inches from the band. There was no movement of nitrate towards the ditch, opposite to the direction of water movement.

With an additional 24 hours of irrigation (Fig. 1 and Table 1), the nitrate movement occurred in a similar form but was more extensive. The greatest difference was an increase in nitrate concentration 4

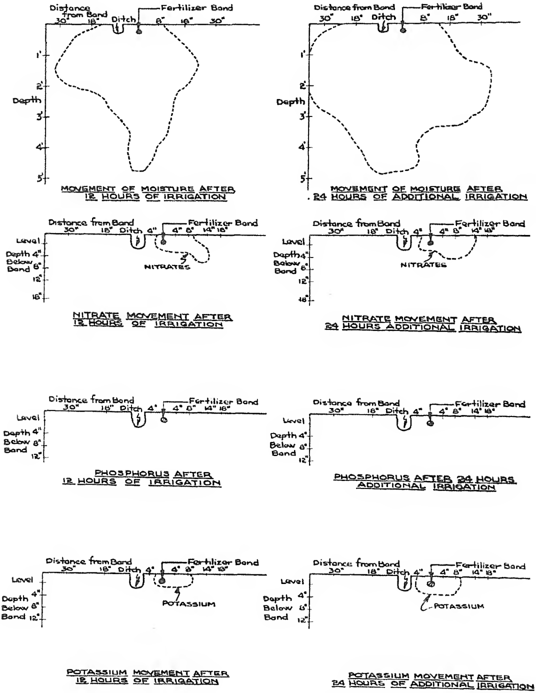

FIG. 1.—A comparison of the movement of certain fertilizer constituents with irrigation.

inches toward the irrigation ditch. The downward penetration of nitrate was also similar with a movement 6 inches further away from the ditch and band.

TABLE 1.—*Concentration of fertilizer constituents at certain distances from fertilizer band after irrigation.*

Sample No.	Distance from band		After 12-hour irrigation				After additional 24-hour irrigation				
	Below, in.	To side, in.*	NO_3, p.p.m.†	P, p.p.m.‡	K, p.p.m.§	Cl, p.p.m.†	NO_3, p.p.m.†	P, p.p.m.‡	K, p.p.m.§	Cl, p.p.m.†	K, p.p.m.†
1	4	0	1.1	634.5	368.3	0	0.7	699.3	449.7	0	73.3
2	8	0	0.2	661.5	110.8	0	0.4	621.0	151.2	0	40.4
3	12	0	0	680.4	121.9	—	0	679.1	107.5	0	—
9	0	4R	93.0	626.4	2,289.1	15.9	37.2	629.1	2,946.1	31.37	1,606.7
10	0	8R	62.0	639.9	218.4	20.2	60.8	650.7	242.5	14.36	64.8
11	4	8R	0.5	639.9	228.1	0	4.6	645.3	174.0	0	39.1
12	8	8R	0.2	666.9	149.9	0	0.5	669.6	183.8	0	35.8
33	0	4L	0.4	639.9	245.7	0	29.1	664.2	231.4	2.13	55.4
34	4	8L	0.9	637.2	156.4	0	0.5	629.1	224.9	0	43.7
35	8	8L	3.0	666.9	162.9	0	0.2	677.7	340.2	0	82.8
56	0	14R	0.2	677.7	232.7	0	1.7	639.9	117.3	0	43.7
57	4	14R	13.0	629.1	195.5	0	0.5	621.0	143.4	0	16.3
58	8	14R	0	626.4	104.3	0	0.2	661.5	138.2	0	32.6

*R signifies to the right and L to the left.
†Water extract.
‡0.2 N nitric acid extract.
§1.0 N ammonium acetate extract.

PHOSPHORUS

The differences in amounts of soluble phosphorus around the fertilizer band were small (Table 1). No movement of phosphorus was indicated by samples taken 4 inches from the fertilizer after either 12 hours or an additional 24 hours of irrigation (Fig. 1).

POTASSIUM

With either 12 or an additional 24 hours of irrigation, the highest concentration of extractable potassium was in a sample taken 4 inches from the band in the direction of the water movement (Fig. 1). The extractable potassium from the other samples had low values, but tests for chlorides (Table 1) indicated a potassium movement 8 inches horizontally from the band. The only difference between the two irrigations in the movement of potassium was that the chloride tests indicated a potassium movement 4 inches towards the ditch with the 24-hour irrigation. No downward movement of potassium in the profile was indicated.

Water extracts of soils when tested for potassium (Table 1) gave values comparable to those obtained with the ammonium acetate extracts, although the values were much lower.

Since the study indicated that the fertilizer movement in the soil was not very extensive, it was concluded that even under irrigation the method of placing fertilizer would be an important consideration.

FIELD TRIALS IN THE PLACEMENT OF FERTILIZERS ON CORN AND BEANS

The field used for the fertilizer placement studies with corn and beans was a portion of the same field as that used for the studies of fertilizer movement under irrigation. Prior to planting, the field was irrigated, plowed, packed, harrowed, and floated to make a smooth surface from which to gauge the depths of planting and fertilizing.

FERTILIZER PLACEMENT AND IRRIGATION METHODS WITH CORN

A 90-day strain of Thayer Yellow Dent corn was selected. On May 18 it was drilled 1½ inches deep in rows 30 inches apart. The plats were laid out 20 feet long and 4 rows wide. A check plat with no fertilizer treatment was included with every seven plats. All treatments were made in duplicate. Two fertilizers, ammonium sulfate (21% N) and treble superphosphate (42% P_2O_5), were used. Sodium nitrate was not used because on this type of soil further additions of sodium have been found to be undesirable (7). All side placements of fertilizer were made with a remodeled hand drill. The fertilizers were weighed and distributed at various depths and distances as indicated in Tables 2 and 3. A specially made shoe, making a fertilizer band 1 inch wide, was used and proper distances from the seed were obtained through the use of a gauge attachment. Where the fertilizer was applied with the seed, the fertilizing and planting were done by hand.

The corn was irrigated June 18, July 9, July 31, and August 19, using regular field practices. When about 18 inches high, the corn was thinned to single plants at 1-foot intervals in the rows. Thick planting was originally necessary due to the possibility of wireworm and pheasant injury to the stand.

RESULTS WITH CORN

Where 84 pounds of nitrogen per acre were applied in the various placements, a decidedly favorable response with respect to yield was obtained in all the plots except one (Table 2). The outstanding placement was two parallel bands 2 inches to the side and 2 inches below the seed, although a band 4 inches to the side and 2 inches below the seed was also very effective. A single band 2 inches to the side and 2 inches below the seed ranked third in yield. The poorest yield was

TABLE 2.—*The yield of irrigated corn with various placements of nitrogen alone and in combination with phosphorus.*

Plat No.	Number of bands	Distance from side of seed, in.	Depth below seed, in.	Grain yield in bushels per acre*: Fertilizer plat	Nearest check	Average increase over checks	Grain yield in bushels per acre*: Fertilizer plat	Nearest check	Average increase over checks
				Nitrogen, 42 Pounds per Acre			Nitrogen, 84 Pounds per Acre		
17-1	2	2	2	24.10	5.86		49.00	9.72	
16a-1a	2	2	2	59.78	66.44	5.79	67.37	14.65	46.00
19-4	2	4	2	29.82	5.86		8.79	9.72	
19a-3a	2	4	2	55.52	21.03	29.22	60.71	12.52	23.63
21-6	1	0	2	25.03	5.86		3.06	9.72	
21a-5a	1	0	2	16.11	21.03	7.12	20.64	12.52	0.73
23-8	1	2	2	19.17	5.86		19.97	9.72	
23a-7a	1	2	2	63.51	21.03	27.89	62.58	12.52	30.15
26-10	1	4	2	33.82	14.65		33.82	15.58	
25a-10a	1	4	2	60.98	21.03	29.56	63.91	12.52	34.81
28-13	1	2	0	21.93	14.65		38.88	15.58	
28a-13a	1	2	0	52.59	21.03	19.37	50.19	21.03	26.23
				Nitrogen, 42 Pounds $+P_2O_5$, 52.5 Pounds per Acre			Nitrogen, 84 Pounds $+P_2O_5$, 105 Pounds per Acre		
18-3	2	2	2	17.44	5.86		35.42	9.72	
18a-2a	2	2	2	62.04	66.44	3.59	48.73	14.65	29.89
20-5	2	4	2	29.42	5.86		24.10	9.72	
20a-4a	2	4	2	54.99	21.03	28.76	49.79	12.52	25.82
22-7	1	0	2	30.36	5.86		7.46	9.72	
22a-6a	1	0	2	26.89	21.03	15.18	18.51	12.52	1.86
25-9	1	2	2	35.15	14.65		37.41	15.58	
24a-9a	1	2	2	49.79	21.03	24.63	63.11	12.52	36.21
27-12	1	4	2	71.90	14.65		38.74	15.58	
26a-11a	1	4	2	76.29	21.03	56.25	55.12	66.44	5.74
30-14	1	2	0	33.55	14.65		43.94	15.58	
29a-13a	1	2	0	55.79	21.03	26.83	90.00	66.44	25.96
15	1	Over	1†				3.06	15.58	
14a	1	Over	1†				0.00	66.44	−39.48
16	1	0	0				0.00	15.58	
15a	1	0	0				0.93	66.44	−40.54

*Basis of 8% moisture.
†Over the seed.

obtained on the plat where the fertilizer was placed directly below the seed. This placement, however, outyielded the check plats, although it had only one third the stand.

Somewhat similar results were obtained with combinations of 84 pounds of nitrogen and 105 pounds of P_2O_5 per acre. A band 2 inches to the side and 2 inches below the seed ranked first, two parallel bands 2 inches to the side and 2 inches below the seed ranked second, and one band 2 inches to the side level with the seed was third. Again the fertilizer placed directly below the seed definitely injured the stand. The plots with the fertilizer placed in contact with the seed and over the seed gave almost no yield whatever, due to decreased stands.

In comparing nitrogen alone with a combination of nitrogen and phosphorus, there was very little difference in yield. When 42 pounds of nitrogen were applied either alone or with 52.5 pounds of P_2O_5 per acre, the outstanding plats were one band 4 inches to the side and 2 inches below the seed and two bands 4 inches away and 2 inches below the seed. The one band 2 inches to the side and 2 inches below the seed was in third place in one case and fourth in another, being almost the same as a similar band level with the seed. The lighter applications of fertilizer 2 inches below the seed gave appreciable yield increases over the check plats, but the stand was again seriously reduced (Table 2). The placement with 2 bands on each side 2 inches to the side of the seed and 2 inches below did not do as well as the other placements with the lighter fertilizer application.

The differences between the nitrogen used alone and with phosphorus did not indicate any appreciable additional yield responses from the phosphorus. The excessively high yields for plats 17a, 26a, and 27 were probably due to the natural fertility differences in the soil.

It may be concluded, therefore, that the best placement methods when using 84 pounds of nitrogen per acre on corn are two parallel bands 2 inches to the side and 2 inches below the seed or one band either 2 or 4 inches to the side and 2 inches below the seed.

When using 42 pounds of nitrogen either one or two bands 4 inches to the side and 2 inches below the seed or one band 2 inches to the side and either 2 inches below or level with the seed seemed to give the best yields.

FERTILIZER PLACEMENT AND IRRIGATION METHODS WITH BEANS

The Red Mexican variety of bush beans was selected for the experiment since it is resistant to diseases prevalent in the district (2). The plot size and row spacing were the same as for the corn. Nitrogen was applied at two rates equivalent to 31.5 pounds and 63 pounds per acre in the form of ammonium sulfate and phosphorus at rates of 42 pounds and 84 pounds of P_2O_5 per acre in the form of treble superphosphate. The placements of these fertilizers are indicated in Table 3.

The beans were irrigated June 2, June 18, July 9, July 31, and August 19.

RESULTS WITH BEANS

Sixty-three pound applications of nitrogen gave reduced yields of beans with all placements as compared with the check plots, except

in a placement consisting of a single band either 2 or 4 inches to the side and 2 inches below the seed. Each of these placements, however, showed variations in yields from duplicate plots. When 84 pounds of P_2O_5 were added per acre in combination with 63 pounds of nitrogen, the single band placement 2 inches to the side and either 2 inches below or level with the seed gave an increased yield. Both of these placements, however, showed negative increases on one or more plats.

With the placements using 31.5 pounds of nitrogen per acre (Table 3), an increase in yield of beans was obtained by placing the fertilizer

TABLE 3.—*The yield of irrigated beans with various placements of nitrogen alone and in combination with phosphorus.*

Plat No.	Number of bands	Distance from side of seed, in.	Depth below seed, in.	Bean yield in bushels per acre			Bean yield in bushels per acre		
				Fertilizer plat	Nearest check	Average increase over checks	Fertilizer plat	Nearest check	Average increase or decrease over checks
				Nitrogen, 31.5 Pounds per Acre			Nitrogen, 63 Pounds per Acre		
17 –1	2	2	2	30.07	36.01		34.87	36.01	
16a–1a	2	2	2	29.50	34.07	−5.25	32.01	33.50	−1.31
19 –4	2	4	2	40.59	36.01		32.01	36.01	
19a–3a	2	4	2	29.61	29.21	2.49	29.27	34.64	−4.68
21 –6	1	0	2	10.06	36.01		2.29	36.01	
21a–5a	1	0	2	1.49	29.21	−26.83	7.55	34.64	−30.40
23 –8	1	2	2	34.98	36.01		34.30	36.01	
23a–7a	1	2	2	33.15	29.21	1.45	43.33	34.64	3.49
26 –10	1	4	2	24.81	33.50		36.13	24.92	
25a–10a	1	4	2	30.41	29.21	−3.74	32.13	34.64	4.35
28 –13	1	2	0	29.38	33.50		26.87	24.92	
28a–12a	1	2	0	39.10	29.21	2.88	30.30	34.07	−0.91
				Nitrogen, 31.5 Pounds $+P_2O_5$, 42 Pounds per Acre			Nitrogen, 63 Pounds $+P_2O_5$, 84 Pounds per Acre		
18 –3	2	2	2	41.96	36.01		28.70	36.01	
18a–2a	2	2	2	26.52	34.07	−0.80	25.04	33.50	−7.88
20 –5	2	4	2	41.50	36.01		28.47	36.01	
20a–4a	2	4	2	32.58	29.21	4.43	38.30	34.64	−1.94
22 –7	1	0	2	7.55	36.01		8.35	36.01	
22a–6a	1	0	2	19.21	29.21	−19.23	9.60	34.64	−26.38
25 –9	1	2	2	40.59	33.50		35.10	24.92	
24a–9a	1	2	2	31.55	29.21	4.71	31.21	34.64	3.37
27 –12	1	4	2	28.24	33.50		24.35	24.92	
26a–11a	1	4	2	38.41	29.21	1.97	24.92	34.07	−4.86
30 –14	1	2	0	34.07	33.50		34.18	24.92	
29a–13a	1	2	0	42.30	29.21	6.83	29.50	34.07	2.34
15	1	Over	1*	——	——	——	22.29	24.92	
14a	1	Over	1*	——	——	——	6.97	34.07	−14.86
16	1	0	0	——	——	——	8.12	24.92	
15a	1	0	0	——	——	——	22.52	34.07	−14.17

*Over the seed.

in two bands 4 inches to the side and 2 inches below the seed. Other placements did not produce yields consistently above the yields of check plots.

Using a combination of 31.5 pounds of nitrogen and 42 pounds of P_2O_5 per acre, the best placement methods were either two bands 4 inches to the side and 2 inches below the seed or a single band 2 inches to the side and 2 inches below or level with the seed.

In summarizing the yield data for all the placement methods on beans, it is evident that an application of 63 pounds of nitrogen and 84 pounds of P_2O_5 per acre was too high to give an accurate indication of the best method of placement since it generally reduced the stands. With one-half the amount of nitrogen and phosphorus, more consistent results were obtained. The placement with two bands 4 inches to the side and 2 inches below the seed ranked first, with a single band 2 inches to the side and 2 inches below the seed ranking second.

Fertilizer with the seed or an inch above the seed caused a very severe injury to the stand of beans, with usually only a few plants surviving.

Although Table 3 shows increases in yields of beans with certain placements, it is also evident that the variations between the check plats are as great as the increases shown. It may be concluded, therefore, that no definite increases in yields were obtained from the use of the nitrogen fertilizer alone or in combination with the phosphorus fertilizer. It did indicate, however, that certain placements were detrimental to the stand and seriously reduced yields.

SUMMARY

The movement of nitrogen, phosphorus, and potassium in a mixed fertilizer applied to Sagemoor fine sandy loam under irrigation was investigated in order to determine the importance of localized fertilizer placement when irrigation water might move the fertilizer in the soil. It was found that highly soluble nitrogen and potassium fertilizers did not penetrate downwards with the water to any appreciable extent, but they did tend to move laterally with the water. The strongest concentrations were found from 4 to 8 inches from the fertilizer band after the water had penetrated over 4 feet into the soil with 12- and 24-hour irrigations.

The movement of phosphorus was negligible as determined by fifth normal nitric acid extracts.

Since there was only a limited fertilizer movement in the soil with irrigation, the importance of localized fertilizer placement studies was evident. Fertilizer placement studies were accordingly made in field trials with corn and beans, using nitrogen and phosphorus fertilizers in the form of sulfate of ammonia and treble superphosphate, respectively. It was evident from the data obtained that fertilizers placed with the seed, 1 inch above the seed, or 2 inches directly below the seed were unsatisfactory methods of placement.

With applications of 84 pounds of nitrogen per acre as ammonium sulfate, the best placement methods for corn were, in the order named, two bands 2 inches to the side and 2 inches below the seed, a single

band 2 inches to the side and 2 inches below the seed, and a single band 4 inches to the side and 2 inches below the seed.

With applications of 42 pounds of nitrogen per acre as ammonium sulfate, the single band 4 inches to the side and 2 inches below the seed gave the best results, although application in two bands 4 inches to the side and 2 inches below the seed and a single band 2 inches to the side and 2 inches below the seed were satisfactory.

No increase in corn yield was evident from the addition of either 52.5 pounds or 105 pounds of P_2O_5 as treble superphosphate per acre with the various localized placement methods.

When large amounts of nitrogen fertilizer alone or in combination with a phosphorus fertilizer were applied to beans, increases in yields were negative or doubful in most cases.

With smaller amounts of fertilizer applied to beans such as 31.5 pounds of nitrogen per acre as ammonium sulfate or in combination with 42 pounds of P_2O_5 per acre as treble superphosphate, it was found that certain placements were less injurious to the stand than others. The best results were obtained with placements in two bands 4 inches to the side and 2 inches below the seed.

No definite yield increases of beans were obtained on this soil from the use of the nitrogen fertilizer alone or in combination with the phosphorus fertilizer. Had this crop been more responsive to fertilizer, the effects of the different placements would probably have been modified.

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DIFFERENCES IN PLANT TYPE AND REACTION TO RUST AMONG SEVERAL COLLECTIONS OF *PANICUM VIRGATUM* L.[1]

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SWITCHGRASS, *Panicum virgatum* L., is an important forage grass and produces a good yield of hay. It is grazed in the younger stages of growth, since the palatability decreases as the plants become coarse later in the growing season. Hoover[3] described switchgrass as an outstanding grass for use in erosion control. In revegetation plantings, switchgrass is used in mixtures with other tall grass species.

Switchgrass occurs more abundantly in the low prairies along streams and rivers. It comprises approximately 5% of the upland grasses in the bluestem pasture section of Kansas. It occurs on sandy upland soil or any lowland soil of western Kansas, and on all soils of the eastern part of the state. Hitchcock[4] gives the range as from Quebec and Maine to Montana south to Florida, Nevada, Arizona, Mexico, and Central America.

Collections of switchgrass made by various representatives of the U. S. Dept. of Agriculture in different parts of the United States were available for testing in the Soil Conservation Service Nursery, Manhattan, Kans. The different accessions were grown for the purpose of making initial observations regarding adaptation and usefulness for revegetation plantings for erosion control.

Some of the accessions represent large acreages of native grassland from which seed is available for future planting if the type proves desirable for general erosion control plantings. Other accessions, such as individual plant selections cannot be obtained from native stands in a quantity sufficient for revegetation plantings, but can be increased from the nursery rows.

Nursery plantings were made in April 1937, April 1938, and June 1939. Sufficient seed of most of the accessions was available in practically all cases for three 10-foot rows spaced 2 feet apart. The nursery soil is a fertile sandy loam, characteristic of lowland in the Kansas River Valley.

Considerable difference was observed in the type of growth produced by the various accessions. Some were coarse, tall, and late

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[3]Hoover, M. M. Native and adapted grasses for conservation of soil and moisture in the Great Plains and western states. U. S. D. A. Farmers' Bul. 1812. 1939.

[4]Hitchcock, A. S. Manual of the grasses of the United States. U. S. D. A. Misc. Pub. 200. 1935.

maturing. Others were fine-stemmed, leafy, medium in height, and early in maturity. The accessions were consistent in the type of growth produced each year.

Several rusts are known to attack switchgrass but the one most commonly observed on that host in central United States is *Uromyces graminicola* (Burr.).[5] This rust was unusually abundant on switchgrass growing in the Soil Conservation Service grass nursery at Manhattan, Kans., in 1939. The differences in susceptibility of some regional collections are worthy of note.

Rust notes were taken on October 19 and 20, 1939, at which time resistant strains still were green and vigorous, there having been only traces of frost before those dates. Rust was recorded in terms of percentage infection, using the scale devised by the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, for use in recording rust infection on cereals. The percentage infection on leaves, stem below the flag leaves (mostly leaf sheaths), peduncles, and panicles was recorded. In order to obtain a single measure of infection for each strain, the four percentages obtained were averaged.

Besides the percentage of infection on the various strains, records also were made of the size of uredia, the presence of flecking, and the percentage of leaves killed by rust. The more resistant collections not only had lower percentages of infection, but the uredia were smaller than those on susceptible types. Flecking was abundant on the leaves of some of the most resistant collections. Many of the leaves of the more susceptible strains were prematurely killed by rust, while the leaves of rust-free types remained green until killed by frost.

VEGETATIVE CHARACTERISTICS OF DIFFERENT ACCESSIONS OF SWITCHGRASS

Data are presented in Table 1 giving the relative ranking of the accessions on the basis of leafiness, forage yield, seed production, coarseness, and basal area for 1937 and 1938 plantings. Ranking from 1 to 10 was used, with the most desirable expression of the character designated as "1" and the undesirable expression of the character as "10". Measurements were recorded at the end of the 1939 growing season for plant height, leaf width, and stem diameter at the third internode above the ground level. Basal area refers to the relative area occupied at ground level at the end of the growing season. The time of full flower and maturity are also given in Table 1.

Groups were determined on the basis of similarity of type and geographical location of the source. Collections from Nebraska, group 1, were low in stature, early in maturity, and relatively leafy. The period of vegetative growth was very short. The first inflorescenses began emerging June 11. This is objectionable because the grass becomes coarser and less palatable when seed stalks start to appear. Seed production for these accessions was low, with an average relative rank of 8.3. The reason for this will be discussed later under the heading of rust infection.

[5]ARTHUR, J. C. Manual of the rusts of the United States and Canada. Purdue Research Foundation, Lafayette, Ind. 1934.

The collections from Colorado, group 2, represented a type from a higher altitude and therefore were similar in several respects to the northern type. They were low in forage yield and early in maturity. The stature was low, but slightly higher than the northern group. The average stem diameter, 3.10 mm, was greater by 0.47 mm than the stem diameter for the northern group. The Colorado collections, on the average, were slightly coarser than those from Nebraska.

The two collections from Alliance, Nebr., group 3, were somewhat taller and later in maturity than either of the above collections. They approach the type found in Kansas.

The Kansas collections, group 4, included eight accessions. Except for G152 and G211 which came from Seward County in the southwestern corner of the state, the Kansas accessions were higher in forage and seed yields, taller, and later in maturity than the groups discussed above. Later maturity is desirable in providing a longer grazing period before the seed stalks appear, after which time the plants become too coarse and stemmy for utilization.

The two accessions from southwestern Kansas were apparently affected by the higher altitude, favoring earliness. The low rainfall and high wind velocity on the high plains have probably been factors in the natural evolution of a type that is less erect, slightly coarser, and less leafy than the typical eastern Kansas strains. These two accessions average 5 inches less in height than the four accessions from Colony, Kans., located in southeastern Kansas. Stem diameters average slightly greater for the southwestern accessions.

The fifth group represented a series of plant selections made at Blackwell, Okla., in 1934 by the senior writer. Seed was obtained from individual plants growing in native stands along the roadside. Selection was made on the basis of leafiness, rust resistance, fine stems, and seed production. These accessions, especially G208, have proved to be superior for the plant characters desired.

Accession G208 had a high proportion of leaves to stems and was given a relative rating of 1 for this character. It was medium in height and low in stem diameter. While in total yield, this accession was only average, the high proportion of leaves to stems, as well as relative quality, justified the selection of this strain over others that produced a greater total amount of forage. This selection was 10 to 15 days later in producing seed stalks than the southeastern Kansas accessions. The time of maturity, September 30, approaches the latest date that a strain can safely mature at Manhattan, Kans. The average date of first frost is October 15. Many more green leaves remained on strain G208 at frost time than on the Kansas or northern collections.

The collections for group 6 were made in the vicinity of Muskogee, Okla., on lowland along the Arkansas River. They were from bulk seed supplies. The type was coarse and tall when grown in the nursery. Some of the seed matured, but many of the later spikelets were injured by frost. All of the plants were consistent for the characters described which were undesirable from a forage or economic point of view.

TABLE 1.—*Relative rank and measurement of vegetative characters and percentage rust infection for 26 accessions of Panicum virgatum (L.) planted in 1937 and 1938, U. S. Dept. of Agriculture, Soil Conservation Service Nursery, Manhattan, Kansas.**

Acc. No.	Source	Relative rank†					Height in inches	Leaf width, mm	Stem diameter, mm	Date full flower	Date mature	Percentage rust
		Leafiness	Forage yield	Seed production	Coarseness	Basal area						
				Group I								
G 180	North Platte, Nebr.	3	9	8	3	5	48	9.35	2.24	July 7	Aug. 14	51
KG 568	O'Neill, Nebr.	5	10	9	3	6	46	8.35	2.31	July 11	Aug. 14	40
G 200	O'Neill, Nebr.	4	9	8	3	5	50	8.39	3.33	July 1	Aug. 14	—
	Mean	4	9.3	8.3	3	5.3	48	8.67	2.63	July 6	Aug. 14	45.5
				Group II								
KG 642	Greeley, Colo.	7	8	7	5	6	53	7.85	3.13	July 11	Aug. 14	46
KG 656	Greeley, Colo.	7	8	7	5	6	50	8.77	3.09	July 11	Aug. 14	51
KG 657	Ft. Collins, Colo.	5	6	6	5	6	53	8.82	3.09	July 11	Aug. 12	36
	Mean	6.3	7.3	6.7	5	6	52	8.48	3.10	July 11	Aug. 13	44.3
				Group III								
G 201	Alliance, Nebr.	4	6	4	6	4	56	9.62	2.98	July 28	Aug. 31	23
G 202	Alliance, Nebr.	4	6	4	6	4	56	8.71	2.55	July 29	Aug. 31	21
	Mean	4	6	4	6	4	56	9.16	2.76	July 29	Aug. 31	22.0

						Group IV						
G 122(a)	Colony, Kans.	3	5	2	4	2	62	8.88	3.42	Aug. 14	Sept. 20	38
G 207	Colony, Kans.	3	5	3	4	3	61	9.69	3.05	Aug. 15	Sept. 25	17
G 122(b)	Colony, Kans.	3	4	2	4	4	64	9.48	3.11	—	—	38
KG 493	Colony, Kans.	3	4	2	5	4	64	9.64	3.13	Aug. 20	Sept. 25	30
KG 488	Neodesha, Kans.	3	4	2	5	4	62	9.60	3.24	Aug. 20	Sept. 25	32
KG 681	El Dorado, Kans.	3	4	2	4	4	56	9.48	3.07	Aug. 12	Sept. 20	32
G 152	Hayne, Kans.	4	6	6	6	3	58	9.57	3.41	July 15	Aug. 27	44
G 211	Hayne, Kans.	5	4	6	6	3	58	11.07	3.51	July 15	Aug. 22	48
	Mean	3.4	4.5	3.1	4.8	3.4	60.6	9.68	3.24	Aug. 7	Sept. 14	34.9
						Group V						
G 208	Blackwell, Okla.	1	5	2	1	2	59	8.15	1.91	Aug. 30	Sept. 30	Trace
G 209	Blackwell, Okla.	2	4	2	3	4	64	9.75	2.49	Aug. 18	Sept. 30	4
G 210	Blackwell, Okla.	2	4	2	3	4	64	8.86	2.32	Aug. 19	Sept. 30	11
G 205	Blackwell, Okla.	2	5	4	2	4	61	8.59	2.53	Aug. 15	Oct. 5	5
	Mean	1.8	4.5	2.5	2.3	3.5	62	8.84	2.31	Aug. 21	Oct. 1	5
						Group VI						
G 167	Oklahoma	9	1	5	10	5	95	11.91	5.89	Aug. 25	Oct. 15	Trace
G 203	Muskogee, Okla.	9	1	6	10	5	100	11.37	5.97	Aug. 25	Oct. 15	0
G 204	Muskogee, Okla.	9	1	6	10	5	100	12.45	5.44	Aug. 25	Oct. 15	0
G 206	Muskogee, Okla.	9	1	6	10	5	100	12.41	5.15	Aug. 25	Oct. 15	0
KG 515	Vernon, Texas	8	1	9	10	6	82	11.18	4.58	Aug. 24	Oct. 15	Trace
KG 638	Schulenberg, Texas	3	2	10	8	6	72	14.21	5.26	Sept. 30	not matured	0
	Mean	7.8	1.2	7.0	9.7	5.3	91.5	12.25	5.38	Sept. 1	Oct. 15	Trace

*Accession numbers with G were planted in 1937. KG accessions numbers were planted in 1938. All data were obtained at end of growing season 1939.
†The most desirable expression of the character designated as 1, the most undesirable as 10.

The forage yield of group 6 was the highest for any switchgrass accessions in the nursery. The relative rank of 1.2 for forage yield, however, was equally discounted by a rank of 9.7 for coarseness. The stems were extremely heavy with an average diameter of 5.38 mm.

The collection from Schulenberg, Texas, is characterized by leafiness, extremely wide leaves, coarseness, and lateness. The inflorescenses were injured by frost in the flowering stage, therefore, viable seed was not produced.

Some of the variation in type of vegetative growth produced by the different accessions is shown in Fig. 1. The plants were removed from the 10-foot rows and photographed July 31, 1939. Accession G122 and G208 represent the leafier types. KG642 was the only accession in the photograph that had produced inflorescenses this early in the season. KG638 was very late in development and G167 was extremely coarse and tall.

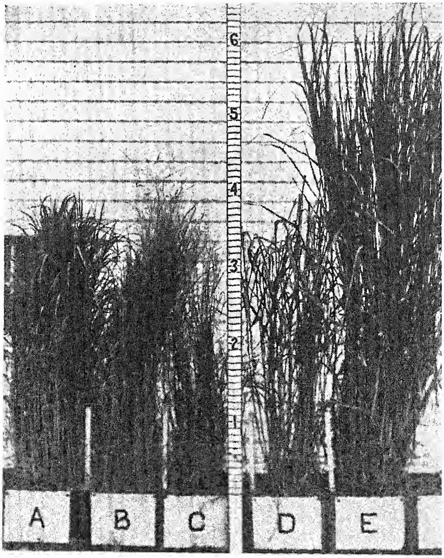

FIG. 1.—Variations in type of vegetative growth of switchgrass accessions from the following sources: (A) G122, Colony, Kan.; (B) G208, Blackwell, Okla.; (C) KG642, Greeley, Colo.; (D) KG638, Schulenburg, Tex.; and (E) G167, Pryor, Okla.

Relative ranking and measurements for the 1939 plantings of switchgrass accessions are given in Table 2. A few of the same accessions used in 1937 and 1938 were again planted in 1939, and several new accessions were added. The collections fall into the same groups as presented in Table 1 for the older plantings. This series was approximately 3 weeks later in development than the 1937–38 series. The seed was planted late in May and some time was required for the plants to become established.

More variations can be observed within the groups for the 1939 series than the 1937–38 series. These differences were accentuated by a serious rust infection.

The two collections from Woodward, Okla., brought two different types from the same general source. KG1077 represented a short type and KG1086 was tall and coarse.

RELATIVE SUSCEPTIBILITY OF REGIONAL COLLECTIONS OF SWITCHGRASS TO RUST

The rust data obtained on the collections planted in 1937 and 1938 are shown in Table 1.

Of the nine collections from Oklahoma, five were the tall, coarse, and late type found in the lowlands of the southern states. All of these were highly resistant, three of them showing no uredia while the remaining two had only traces of infection on the leaves. The other four collections from Oklahoma were upland types. One of these, G208, from a single plant collected near Blackwell, Okla., had only 2% infection on the leaves and traces on other parts. This strain seems particularly promising from the standpoint of rust resistance as well as its plant character.

The collections of switchgrass from Kansas resembled the shorter, finer-leafed upland collections from Oklahoma. All, except strain G207 from southeastern Kansas, were classified as susceptible, although there were some differences among them. All but one of the Kansas collections had heavy infections on the leaves and moderate infections on the leaf sheaths, panicles, and peduncles. Accession G207 had very light infections on all parts except the leaves and was easily the most resistant of the Kansas strains.

The three collections from Colorado were short in stature and leafy like the strains of northern origin. They also were very susceptible to rust. Apparently, collections of switchgrass from the higher elevations in the Great Plains are very similar to collections made in the extreme northern part of the United States.

Of four collections from Nebraska, two were very susceptible—one was moderately susceptible, and one was slightly resistant.

There were two collections from Texas, one from Vernon in the Red River Valley and one from Schulenburg near the Gulf Coast. Both were tall, late-maturing types and both were highly resistant to rust.

The second group of collections of switchgrass available for study in 1939 consisted of 20 accessions in their first year of growth. All of the strains headed but were considerably later than the second season plants discussed above. In general, they were shorter in stature than

TABLE 2.—*Relative ranking and measurements of vegetative characters and percentage rust infection for 20 accessions of Panicum virgatum (L.) planted in 1939, U. S. Dept. of Agriculture, Soil Conservation Service Nursery, Manhattan, Kansas.**

Acc. No.	Source	Relative ranking†					Height in inches	Leaf width, mm	Stem diameter, mm	Percentage rust
		Leafiness	Forage yield	Seed production	Coarseness	Basal area				
				Group I						
KG 1054	Mandan, N. Dak.	2	10	10	1	9	19	5.18	1.10	42
KG 568	O'Neill, Nebr.	3	10	10	1	8	23	5.50	1.42	51
G 180	North Platte, Nebr.	2	8	8	2	7	33	5.81	3.16	47
KG 734	O'Neill, Nebr.	2	10	10	1	8	19	4.60	1.30	67
	Mean	2.3	9.5	9.5	1.3	8	23.5	5.27	1.74	51.8
				Group II						
KG 657	Ft. Collins, Colo.	3	5	5	3	4	40	7.08	1.99	35
				Group IV						
KG 493	Colony, Kans.	2	2	5	3	2	44	7.40	2.30	27
KG 1034	Neodesha, Kans.	2	2	2	3	2	46	8.49	2.42	17
KG 488	Neodesha, Kans.	2	2	2	3	2	48	9.44	2.54	17
KG 681	El Dorado, Kans.	2	3	5	3	2	36	6.40	2.07	30
KG 1016	Protection, Kans.	3	5	4	3	3	33	6.91	2.29	31
G 211	Hayne, Kans.	5	8	5	3	2	21	6.44	1.84	31
KG 1077	Woodward, Okla.	3	3	2	3	2	36	7.82	2.75	16
	Mean	2.7	2.6	3.6	3	2.1	37.7	7.56	2.32	24.1
				Group V						
G 208	Blackwell, Okla.	2	2	2	2	2	46	6.91	1.68	4
				Group VI						
KG 1086	Woodward, Okla.	4	2	3	6	3	46	9.87	3.58	2
KG 767	Yukon, Okla.	4	1	7	10	3	48	11.16	3.61	Trace
G 204	Muskogee, Okla.	5	1	6	10	3	49	11.06	4.07	Trace
G 203	Muskogee, Okla.	5	1	6	10	3	50	10.52	3.90	Trace
KG 515	Vernon, Texas	4	1	9	10	3	52	11.01	3.84	Trace
KG 638	Schulenberg, Texas	2	2	10	8	3	37	12.21	3.28	Trace
KG 719	Schulenberg, Texas	2	2	10	8	3	40	12.63	3.07	Trace
	Mean	3.7	3.4	7.3	8.9	3	46	11.21	3.62	Trace

*Data taken at end of growing season.
†The most desirable expression of the character designated as 1, most undesirable as 10.

the 2-year plants, although the difference in height, coarseness of stem, and width of leaf between strains of upland and lowland origin persisted.

The rust data on the accessions in their first season of growth are shown in Table 2. In general, infection was heavier on these than on the older plants. The strains from North Dakota, Nebraska, and Fort Collins, Colo., had very heavy infection on the leaves and leaf sheaths. Infection on the leaves of KG1054 from North Dakota and accessions KG568, G180, and KG734 from Nebraska was so heavy that most of the leaves were dead and dry at the time the rust notes were taken. The rust apparently developed very early on these very susceptible strains and greatly suppressed the heading.

Among the six Kansas collections in their first year of growth none were observed to be highly resistant. All accessions had moderately heavy infections on the leaves, moderate infection on the sheaths, and light to very light infections on peduncles and panicles. The latter may have been partly due to the late emergence of the panicles.

Accession G208 from Blackwell, Okla., maintained the strong resistance it exhibited in the earlier planting, although it had slightly more infection on the leaves and leaf sheaths. All of the remaining Oklahoma accessions were tall, coarse, lowland types and all but one

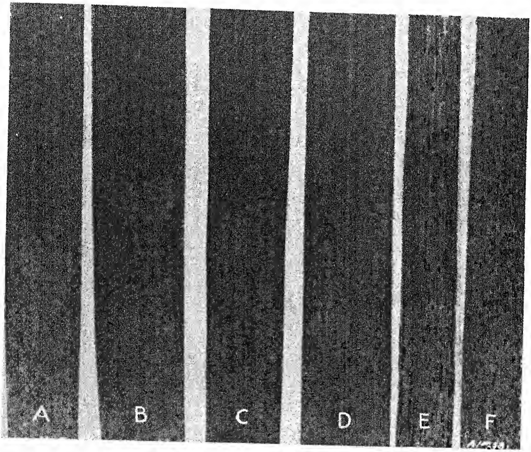

FIG. 2.—Variation in rust infection on switchgrass leaves from different sources: (A) KG638, Schulenburg, Tex.; (B) G203, Muskogee, Okla.; (C) KG515, Vernon, Tex.; (D) G208, Blackwell, Okla.; (E) KG657, Ft. Collins, Colo.; and (F) KG681, El Dorado, Kan.

were highly resistant to rust. Accession KG1086, the lowland strain from Woodward, differed from the others in having slightly more infection on the leaves.

The three first-year accessions from Texas were tall, coarse, and late, as well as extremely resistant to rust like the lowland types from Oklahoma. These strains had occasional small uredia on the leaves but none on other plant parts.

A few of the accessions in both groups of plantings contained both resistant and susceptible strains. KG1016 from Protection, Kans., seemed to contain many plants of both types. A very few susceptible plants were noted in G208, the resistant upland strain from Blackwell, Okla. One or two susceptible plants were found in the tall, coarse accessions G203, G204, and KG638. In these three cases, the susceptible plants were smaller than other plants in the row.

Although only a few collections from southern locations were grown, the results indicate that the tall, coarse lowland types from the south are mostly highly resistant to rust, while the shorter, finer-stemmed upland types from the northern states are susceptible. The variation in amount of infection on the leaves of different accessions is shown in Fig. 2. Flecking can be observed in the leaf of accession G208 from Blackwell, Okla. This is a type of resistance.

SUMMARY

1. Thirty-four accessions of switchgrass from different parts of the Great Plains were tested in the Soil Conservation Service Nursery, Manhattan, Kans., where they were subjected to heavy natural infection by rust (*Uromyces graminicola*).

2. Considerable variation was exhibited in characters which determine usefulness for forage production and erosion control, as well as for resistance to rust.

3. Collections from O'Neill, Nebr., and from North Dakota were low in stature, early in maturity, low in forage yield and seed production, and were extremely susceptible to rust.

4. Collections from lowland in Oklahoma and from southern Texas were tall, coarse, late in maturity, and highly resistant to rust.

5. Kansas collections were intermediate in type and rust reaction. The accessions from western Kansas were lower in stature, earlier, and produced fewer leaves as compared with accessions from eastern Kansas.

6. A plant selection from Blackwell, Okla., G208, had more desirable characteristics than any other accession. It was leafy, fine stemmed, late in maturity, high in seed production, and promising in resistance to rust.

ECOLOGICAL RELATIONSHIPS OF PLAYA LAKES IN THE SOUTHERN GREAT PLAINS[1]

JOHN M. PARKER AND CHARLES J. WHITFIELD[2]

THE playa lake on the Amarillo Experiment Station,[3] consisting of approximately 125 acres, is typical of other similar lakes in the Southern High Plains Area. These lakes or depressions are thought to have been formed by wind erosion. The process of formation of one of these lakes might be summarized as follows: Surface drainage is poor in an area; surface water collects and stands in naturally low spots. This water evaporates, or percolates below the surface, and the low areas are left exposed to the wind. These dried up low areas are more subject to wind erosion than the surrounding country because, first, water has carried fine particles of silt and clay into them, which blow easily when dry,[4] and secondly, a permanent plant cover has a hard time becoming established in an area that is alternately submerged and then completely dried up. As a result, more soil is moved from these low areas and wet weather lakes are formed. In this region, the prevailing wind is from the southwest. Thus, in line with this theory, it might be expected that the north or northeast sides of these lakes would be higher than the south or southwest sides, because the soil would move in a northeast direction and thus would tend to pile up on the north side. By measurement, the north side of the lake on the Amarillo Experiment Station is 16.6 feet higher than the south side. This theory of formation possibly accounts for most of the playa lakes in the High Plains. A few of the lakes may have been formed by ground settlement, due to the removal of soluble materials in the Permian beds which underlie the Tertiary outwash sediments that cover the High Plains.

These lakes constitute the drainage for those parts of the High Plains not drained by major streams or their tributaries. Templin and Shearin[5] characterize these lakes as follows: "The surface of the High Plains is dotted by numerous enclosed flat bottomed depressions, the low parts of which are occupied by intermittent lakes or playas. These depressions reach a maximum size of several square miles, and most of them consist of three parts: (1) A central low flat, occupied by an intermittent lake bed constituting from one-fourth to one-half of the total area of the depression; (2) a surrounding concentric poorly drained flat usually known as 'second bottom'; and (3) an outer surrounding slope from one-eighth to one-fourth mile

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture, Amarillo, Texas. Received for publication September 26, 1940.

[2]Student Assistant and Senior Soil Conservationist, respectively.

[3]The Amarillo Experiment Station, Soil Conservation Service, Division of Research, is located on Highway 66, 14 miles west of Amarillo, Texas.

[4]DANIELS, HARLEY A. The physical changes in soils of the Southern Great Plains due to cropping and wind erosion and the relation between the sand $+\frac{\text{silt}}{\text{clay}}$ ratios in these soils. Jour. Amer. Soc. Agron., 28:570–580. 1936.

[5]TEMPLIN, E. H., and SHEARIN, A. E. Soil survey of Potter County, Texas. U. S. D. A. Series 1929, No. 23.

wide, with a gradient sufficiently steep to cause some soil erosion. These depressions occur at intervals of about 2 or 3 miles and constitute about one-tenth of the total area of the High Plains in Potter County.[6] In the county the High Plains lie at an elevation ranging from 3,500 to 3,800 feet above sea level."

Detailed ecological studies were initiated on these lakes; first, because they occupy rather large acreages; second, in most cases the vegetative cover is inadequate to prevent erosion; and third, to determine the possibilities of improving their economic value by increasing the carrying capacity and controlling erosion by the establishment of a permanent grass cover.

ECOLOGICAL RELATIONSHIPS

During the past several years, general ecological surveys were made of numerous playa lakes over the High Plains. Buffalo grass, *Buchloe dactyloides* (Nutt.) Engelm, was found to be the most important perennial grass around the lakes and was observed in some instances to cover a lake bottom completely. Because of the importance of this species detailed studies were initiated in July 1940 on the lake located on the Amarillo Experiment Station to determine (1) the extent that buffalo grass was growing in the bottom of the lake, (2) its abundance at different levels, (3) the relationship of this grass to other vegetation, and (4) the influence of such factors as topography on its occurrence.

The detailed survey on the station was done with a telescopic alidade and plane table. Ten locations were established and marked by stakes for future reference, and a total of 148 shots were made from these 10 instrument setups. At each point, data were collected on the plant species present as well as their abundance.

In surveying the extent of the buffalo grass, three arbitrary lines were used as a basis for mapping (Fig. 1), namely, (1) edge of maximum stand of buffalo grass, i.e., the line where the solid cover of sod becomes spotty; (2) edge of 50% buffalo grass sod cover, i. e., the line from which, on the side toward the periphery of the lake, more than 50% of the cover is buffalo grass, and on the side toward the center of the lake more than 50% of the cover is composed of other species; and (3) edge of area in which buffalo grass is common, i. e., beyond this line toward the center of the lake only small, scattered, solitary clumps of the grass occur.

Although rather sharp ecotones are to be found in lake vegetation, the three lines which were used are arbitrary and only indicate a transition that is more or less irregular. The lake bottom soil is Randall clay and at the time of the measurements was very dry with open cracks several inches wide and often extending down to a depth of 3 feet or more. This cracking is one of the characteristics of this soil type. Precipitation on the Amarillo Experiment Station for the period January through July 1940 was 6.45 inches as compared to a long time average for the same period of 12.25 inches.

[6]In Potter County, Texas, alone it is estimated that these lakes cover approximately 58,880 acres.

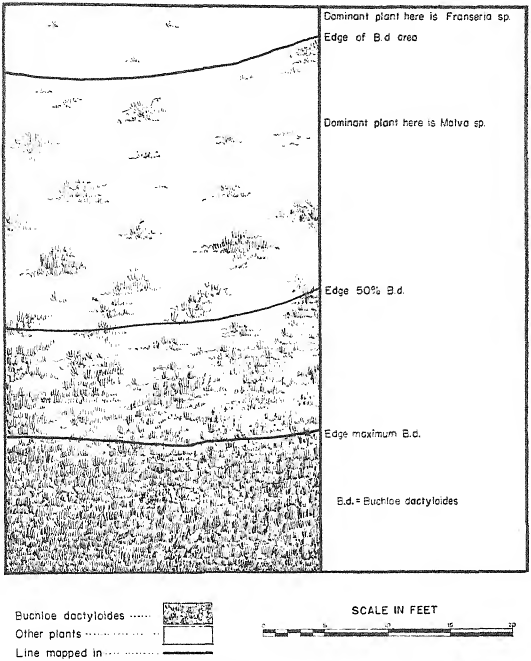

FIG. 1.—Sketch picturing boundary lines set up in mapping the buffalo grass.

EXTENT OF BUFFALO GRASS

Using Templin and Shearin's zonal designations, the bottoms, zone 1, usually contain little or no buffalo grass, while zones 2 and 3 generally have a good stand of sod. This grass evidently cannot stand the prolonged submergence that often occurs in the lower zone after heavy rains. If the lake is of fair size, it will have one or more drainage ways entering it. These usually enter at a low gradient and spread out into an alluvial fan. On the sides where the slope is not so great, i.e., where surface water drains into the lake in a channel, there is less sheet run-off, better sod, and the grass extends farther out into the flat part of the lake (Fig. 2). *Buchloe* spreads out farther into the

flat part of the lake around these fans. On the sides of the depression where the slope is steep, run-off is high and the water will stand the deepest near these steep slopes. Thus, as would be expected, there is little or no buffalo grass to be found in this area.

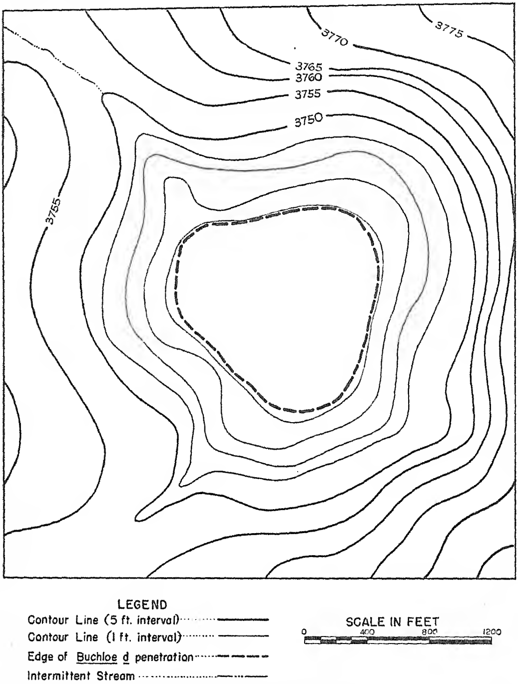

FIG. 2.—Generalized sketch of a playa lake in the High Plains area in the vicinity of Amarillo, Texas, to show the influence of topography on the occurrence of *Buchloe d* in that lake.

OTHER VEGETATION

The most outstanding species of zone 1, just as buffalo grass is in zones 2 and 3, is a gray composite, *Franseria tomentosa* A. Gray, false ragweed. During the hot, dry season of 1940, the plants had made

little growth and, as a consequence, the stalks of the plants of previous years were conspicuous. Two other species rank in nearly equal importance with false ragweed, namely, *Eleocharis palustris* (L.) R. & S., spike-rush, and *Euphorbia marginata* Pursh., snow-on-the-mountain. Species of the sedges, *Carex*, although present, are of minor ecological importance. Other forbs of common occurrence are *Helianthus ciliaris* D. C., blue weed; *Vernonia marginata* (Torr.) Raf., ironweed, *Sphaeralcea* sp., swamp mallow; *Grindelia squarrosa* (Pursh.), gumplant; *Solanum rostratum* Dunal., buffalo bur; and *Salsola pestifer* A. Nels., Russian thistle. A few grasses in addition to buffalo grass, *Agropyron smithii* Rydb., western wheat grass, *Hordeum pusillum* L. Nutt., little barley, and *Schedonnardus paniculatus* (Nutt.) Trelease, tumble grass, are also found. Of these, western wheat grass is the most important. One species belonging to the Pteridophytes, *Marsilea vestita* Hook & Grev., is rather widespread.

DISCUSSION AND CONCLUSION

As a result of study and observation during the past several years, it appears possible to increase the economic value of these playa lakes through the use of soil conservation practices such as terracing and contour furrowing. In 1937, the soil on the lake bottom on the Amarillo Experiment Station was blowing. A rather large area on the north and west was furrowed on the general contour. This emergency listing stopped the blowing and by the end of the growing season of 1939, nearly all the furrows and ridges in zones 2 and 3 were practically completely covered with buffalo grass.

The presence of *Buchloe* greatly increases the chance of securing a permanent grass cover, as it is a stoloniferous perennial that spreads rapidly both vegetatively and by seed. It responds very readily to an increased moisture supply, developing a dense vegetative carpet in depressions and other low areas over the High Plains.

Contour tillage and terracing of cultivated lands around large lakes would appear, therefore, not only to be of value in holding the moisture where it falls and, keeping it out of the lakes, but would also give buffalo grass a chance to spread. On the Amarillo Experiment Station, contour tillage and increased residues are being used to hold the water on the cultivated land, while much of the pasture land around the lake has been contour furrowed in order to keep the water out of the lake bottom. The application of these practices should increase considerably the carrying capacity of these lake pastures in the High Plains.

THE EFFECT OF FERTILIZATION ON THE NITROGEN, ACTIVE PHOSPHORIC ACID, AND ACTIVE POTASH OF A LAKE CHARLES CLAY LOAM[1]

G. S. FRAPS, J. F. FUDGE, AND E. B. REYNOLDS[2]

AN experiment to study the effect of fertilization on the yield of cotton and corn when grown in rotation on a Lake Charles clay loam at Substation No. 3, Angleton, Texas, was started by the Division of Agronomy of the Texas Agricultural Experiment Station in 1930. After eight annual applications, it seemed desirable to determine what differences the continued fertilization over the 8-year period had brought about in the nitrogen, active (0.2N nitric acid soluble) phosphoric acid, active potash, and pH of the soil of the differently treated plots. Results of the study are reported in this paper.

PLAN OF THE EXPERIMENT

The Lake Charles clay loam is a heavy, sticky soil occurring over large areas of the Gulf Coast Prairie of Texas (1)[3], and is a very important soil for crop production. It is usually low in active phosphoric acid and active potash, only moderately supplied with nitrogen, and is very slightly acid (1). A 2-year rotation of cotton and corn was started on an area of this soil type in 1930. The plots were 1/22 acre in size. Fertilizer treatments were replicated four times. Fertilizers of varying formulae and amounts were applied each year to the different plots. The fertilizers were made from sulfate of ammonia, superphosphate, and muriate of potash.

Samples of soil of the plats at depths of 0 to 6 inches and 6 to 12 inches were secured in the fall of 1937 and analyzed for nitrogen, active (soluble in 0.2 N nitric acid) phosphoric acid (3), active potash (4), and pH. Owing to very unfavorable conditions during one year, corn failed completely on two of the four series of plots. Cowpeas were grown on these plots during the summer and plowed under in the fall. Because of this fact, soil samples were secured only from the two series on which corn had grown that year. Twelve samples each of surface soil and subsoil were taken from each plot sampled. These 12 samples were then composited to make the sample used for analysis.

RESULTS

The total quantities of nitrogen, phosphoric acid, and potash applied to the several plots and the average annual yields of lint cotton and corn are shown in Table 1. Cotton and corn responded to nitrogen and to phosphoric acid when accompanied by nitrogen, but they did not respond so strongly to potash.

The average analyses of the surface soils and the subsoils for nitrogen, active phosphoric acid, and active potash are also shown in

[1]Contribution from the Divisions of Chemistry and Agronomy, Texas Agricultural Experiment Station, College Station, Texas. Received for publication October 19, 1940.

[2]Chief, Division of Chemistry, Chemist, and Chief, Division of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 134.

TABLE 1.—*Effect of fertilizer treatment on nitrogen, active phosphoric acid, and active potash in a Lake Charles clay loam.*

Treatment No.	Total nutrients added, pounds per acre			Average yield		Surface soil (0–6 inches)			Subsoil (6–12 inches)		
	N	P_2O_5	K_2O	Cotton, per acre lbs.	Corn, per acre bu.	Nitrogen %	Active phosphoric acid, p.p.m.	Active potash, p.p.m.	Nitrogen %	Active phosphoric acid, p.p.m.	Active potash, p.p.m.
1	0	0	0	302	24.5	0.117	19	102	0.074	9	106
2	0	384	128	358	26.4	0.138	62	156	0.103	13	121
3	128	0	128	342	26.9	0.131	21	106	0.080	11	117
4	128	256	128	388	27.5	0.146	30	126	0.094	14	123
5	128	384	0	369	27.7	0.150	56	108	0.097	11	106
6	128	384	128	389	27.8	0.139	52	117	0.090	12	121
7	256	384	128	429	32.7	0.137	40	103	0.099	14	123
8	256	768	256	442	32.8	0.154	103	111	0.106	15	116
9	320	960	320	495	34.0	0.154	148	140	0.095	17	132
10	512	768	256	506	35.6	0.138	107	140	0.089	14	117
11	512	768	512	521	37.5	0.155	102	129	0.101	13	119
12	640	768	256	512	38.0	0.139	84	104	0.089	13	117
Standard deviation × 2						0.028	82	46	0.028	6	24

Table 1. Analysis of variance showed that there were no significant differences between the analyses of the samples from the duplicate plots, consequently, only the averages are given in Table 1.

At the end of the period, the nitrogen in five of the plots (Nos. 4, 5, 8, 9, and 11) was higher than that in the plot which received no fertilizer (No. 1) by quantities greater than twice the standard deviation of the 24 samples of surface soil. When these results were compared with those from the plot which received no nitrogen but received phosphoric acid and potash, however, the increases were not significant. Neither were they signicant when compared with the average quantity of nitrogen found in the two plots which received no nitrogen (Nos. 1 and 2).

The average percentages of nitrogen in the surface soils of the plots which received totals of 0, 128, 256, 320, 512, and 640 pounds of nitrogen per acre were 0.128%, 0.142%, 0.146%, 0.154%, 0.147%, and 0.139%, respectively. Although there were increases in the nitrogen content, none of the average increases were statistically significant, nor were they regular with increases in the quantity of nitrogen applied, nor between different plots receiving the same quantities. It should be noted, however, that the highest total application of nitrogen, 640 pounds per acre, is equivalent to only about 0.032% of the soil. Nitrogen in plot 12, which received 640 pounds of nitrogen per acre, was only 0.001% higher than in plot 2 which received no nitrogen. Significant increases in yields of both cotton and corn were secured with the higher applications of nitrogen (256 pounds and above), and it is probable that the plants used practically all of the nitrogen added. Some of the variations in nitrogen content may be due to irregularity of the soil. Analysis of variance and a comparison of the increases with the standard deviation of the analyses indicate that nitrogen in these plots was not significantly increased by the application of comparatively large quantities of nitrogen in the fertilizer.

Active phosphoric acid in surface soils which had received 0, 256, 384, 768, and 960 pounds of phosphoric acid per acre (approximately equivalent to 0, 128, 192, 384, and 480 p. p. m.) during the 8-year period averaged 20, 30, 52, 99, and 148 p. p. m. Increases in active phosphoric acid in the surface soil were equivalent to 8, 17, 21, and 29%, respectively, of the quantity added. Analysis of variance showed these variations with treatment to be statistically highly significant. About 80% of the phosphoric acid added either became insoluble in the 0.2 N nitric acid, or was taken up by the plant. The soil thus had a high power of rendering phosphoric acid insoluble in 0.2 N nitric acid.

Corresponding quantities of active phosphoric acid in the subsoils (6 inches to 12 inches) were 10, 14, 12, 14, and 17 p. p. m. While there are slight increases in active phosphoric acid in the subsoils, the only statistically significant increase was in the plot which had received phosphoric acid equivalent to about 480 parts per million. In this plot, the increase in active phosphoric acid amounted to only 7 parts per million. Active phosphoric acid in the surface soil thus increased markedly with an increase in the quantity of phosphoric acid added

to the soil, but there was practically no downward movement of phosphoric acid in this heavy soil.

Active potash ranged from 102 p. p. m. in the plot receiving no fertilizer (No. 1) to 156 p. p. m. in the plots receiving phosphoric acid and potash but no nitrogen (No. 2). This increase was the only increase which exceeded twice the standard deviation of the analyses. Yields of cotton and corn were slightly higher on plot 2 than on plot 1. When the results from these plots (Nos. 1 and 2) are omitted from the calculations, the increases in active potash on all other plots amounted to an average of less than 5% of the quantity of potash added. Active potash in the soils which had received total applications of 0, 128, 256, 320, and 512 pounds of potash per acre averaged 105, 122, 118, 140, and 129 p. p. m., respectively, in the surface soils, and 106, 121, 117, 132, and 119 p. p. m., respectively, in the subsoils. None of these average increases are statistically significant, as indicated either by analysis of variance or comparison with the standard deviation. That these slight differences may be partly due to variations in the native soil is also indicated by the fact that the average analyses for the surface soils agree with those for the subsoils within the limits of error of the estimation. No significant differences, therefore, occurred in the active potash in this soil with variations in potash fertilization. Plants have the power of taking up more potash than they need when abundant supplies are given. The missing potash may have been removed by the plants, or fixed by the soil in forms which are insoluble in 0. 2 N nitric acid.

The pH values of the soils of the different plats are not presented in tabular form because there were no significant differences in pH due to the different treatments. The maximum range in pH of the samples of surface soils from the different plats was from 5.68 to 6.05, with a mean of 5.87; for the subsoils, the range was from 6.17 to 6.72, with a mean of 6.36. The maximum range in pH of the surface soils in normal potassium chloride was from 4.85 to 5.13, with a mean of 5.00; that of the subsoils from 5.04 to 5.49, with a mean of 5.30.

DISCUSSION

The results here reported may be compared with those previously reported for a Lufkin fine sandy loam at College Station, under approximately the same treatments and for a like period of time (2). In the Lake Charles clay loam here reported, the only significant changes were in active phosphoric acid and there was no downward movement of nutrients into the subsoil, although some of the nitrogen after nitrification may have been leached out. In the Lufkin fine sandy loam, the nitrogen, active phosphoric acid, active potash, and acidity were all considerably increased in the surface soil and there was a very significant downward movement of nutrients into the subsoil.

The surface of the Lake Charles clay is a very heavy, plastic clay, high in base exchange capacity and phosphate-fixing power, while that of the Lufkin fine sandy loam is a permeable, friable (when moist) soil with low to intermediate exchange capacity and phosphate-fixing power. Both subsoils are heavy, dense, and impermeable.

SUMMARY

A study was made of the effect of fertilizers added during a period of 8 years in varying quantities and proportions up to maximums of 640 pounds of nitrogen, 960 pounds of phosphoric acid, and 512 pounds of potash per acre, upon the quantities of nitrogen, active phosphoric acid, active potash, and pH of a Lake Charles clay loam at Angleton, Texas.

Nitrogen, active potash, and pH were not significantly changed, either in the surface soil or subsoil. Active phosphoric acid in the surface soil was markedly increased, but the increases accounted for only about 20% of the phosphoric acid added. The active phosphoric acid in the subsoils was increased significantly only in the plat which had received 960 pounds of phosphoric acid, and then the increase amounted only to 7 p. p. m. There was thus no significant penetration of the added nutrients into the lower layers of soil, although some of the nitrogen after nitrification may have been leached out of the zone of soil sampled.

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SOAKING BUFFALO GRASS (*BUCHLOE DACTYLOIDES*) SEED TO IMPROVE ITS GERMINATION[1]

LEON E. WENGER[2]

RESULTS of recent investigations at the Fort Hays Branch of the Kansas Agricultural Experiment Station have indicated that if buffalo grass seed is soaked in tap water for 2 to 4 days, followed by immediate and thorough drying previous to seeding, delayed germination and prolonged dormancy in this species will be largely overcome.

Poor emergence and "near failure" stands commonly resulted from early attempts at seeding, leading to the general belief, as expressed by Savage (2)[3], that buffalo grass cannot be re-established with consistent success by artificial seedings. From field plantings of untreated seed at Hays, it has been consistently observed that emergence is slow and generally unsatisfactory. Frequently, more plants will emerge during the second year than during the first year, indicating that going through a winter season aids the germination of this seed. On several occasions, buffalo grass plants were observed to volunteer as long as 3 years after seeding, despite intervening cultivation and cropping treatments. This latter observation is substantiated by Savage and Runyon (3) in their study of the natural revegetation of abandoned farm land, where they state that seeds of buffalo grass and other hard-seeded species appeared to be capable of remaining in cultivated soils and emerging after several years of cultivation. Similar experiences have been reported by farmers in instances where buffalo grass pastures, plowed and cultivated for as long as 5 years, reverted quite rapidly to buffalo grass upon abandonment.

Additional observations have shown conclusively that the percentage germination of buffalo grass seed increases with age up to 3 or 4 years. Pladeck (1) found that weathered seed germinated better than unweathered seed and concluded that harvesting burs after a period of natural weathering is to be recommended. Greenhouse studies at Hays have shown that clean or hulled caryopses often germinate as high as 70% and 80%, indicating that the scarifying action resulting from the hulling operation is beneficial to immediate germination. The use of 75% sulfuric acid for 105 minutes as a digesting agent was found to be effective in materially increasing the immediate germination of buffalo grass seed in laboratory tests.

The following deductions might be made in evaluating these observations and findings with the possibility of practical farm applica-

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[2]Agent, U. S. Dept. of Agriculture, and Forage Crops Specialist, Fort Hays Branch Agricultural Experiment Station. The writer is particularly indebted to Miss Albina F. Musil, Assistant Botanist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, for making all laboratory tests and reporting her observations and findings.

[3]Figures in parenthesis refer to "Literature Cited", p. 141.

tion: (a) Establishing stands of buffalo grass by planting untreated seed is a long time process not generally conducive to satisfactory results; (b) aging the seed is a slow and costly practice because of the insect and storage problems likely to be encountered; (c) allowing for a period of natural weathering results in low quality seed and lower yields because of a lack of satisfactory harvesting equipment; (d) hulling or cleaning to a pure caryopsis state is impractical because of a lack of both cleaning and seeding equipment suitable for preparing and seeding on the average farm; (e) treating with 75% sulfuric acid is cumbersome and dangerous under ordinary farm conditions.

Soaking the seed in water followed by a thorough drying is an inexpensive, practical method employable on any farm. This treatment can be termed artificial weathering, or aging, and the results obtained from the rapid drying of the seed may be regarded as similar in effect to scarifying. It is also possible that other factors not now recognized may be responsible for part of the increased germination resulting from this treatment.

MATERIALS AND METHODS

High quality buffalo grass seed[4] was put to soak in tap water at room temperature March 11, 1940. At the end of each 24-hour period an equal amount of the seed was removed and dried on window screen. This gave seed with the following treatments to be compared with untreated seed: soaked 24 hours, 48 hours, 72 hours, and 96 hours.

Sufficient seed of each treatment was provided for three plantings in the field each year for 3 years and for four germination tests in the Washington laboratory each year for the same number of years. Field plantings were made as close to the dates of April 15, April 30, and May 15 as was feasible by planting 100 burs in 25-foot rows at a depth of between ½ and ¾ inch. Seven rows of each treatment were planted in a randomized order on each date of seeding. The seed sent to Washington was germinated as described under laboratory results.

Germination results from the field tests are expressed in terms of bur germination only, because of the difficulty of accurately obtaining caryopsis data. Results from the laboratory samples were obtained from single 100-bur tests with germination percentages expressed both in terms of viable bur germination and viable caryopsis germination.

FIELD RESULTS IN 1940

Plantings of treated and untreated seed were made in the field on fallow April 13, April 29, and May 15. Climatic conditions, as will be observed in Table 1, were extremely adverse at the time of and following the first two plantings, particularly in view of the fact that the total precipitation for 1939 was only 15.85 inches and that for the first 3 months of 1940 only 1.90 inches. The soil was dry at the time of the May 15 planting, but good rains were obtained during the subsequent 30-day period.

The beneficial effect of the soaking treatments on the immediate germination of buffalo grass seed can readily be observed in Fig. 1 and Table 2. The May 15 planting gave the highest germination re-

[4]This seed was harvested in July 1938 with a field mower at an optimum stage of ripeness before any natural weathering had resulted.

TABLE 1.—*Daily and total monthly precipitation in inches at Hays, Kansas, for the 3-month period in 1940 during which field germination studies were conducted on the effect of soaking buffalo grass seed.*

Day of month	April		May		June	
	1–15	16–30	1–15	16–31	1–15	16–30
1–16						
2–17		0.66		0.06	0.23	
3–18				0.80		
4–19						
5–20					Trace	
6–21	0.03	Trace		Trace	0.50	0.64
7–22	0.32	Trace			0.53	
8–23			0.07			0.15
9–24	Trace				0.25	
10–25	Trace	Trace				
11–26	0.14				Trace	
12–27		0.04		0.96	0.06	
13–28	*	0.22			Trace	
14–29		0.04†	0.07			
15–30		0.12	‡	0.45		
31						
Total...		1.57		2.41		2.36

*Date of first planting. †Date of second planting. ‡Date of third planting.

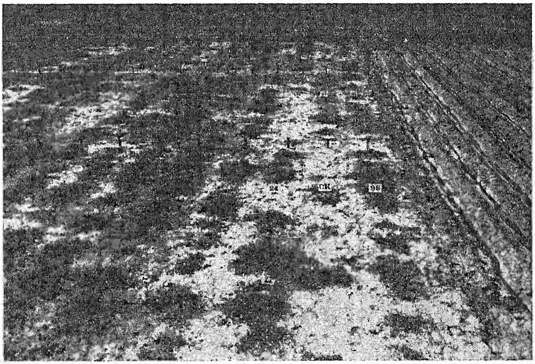

FIG. 1.—The effect of soaking buffalo grass seed in water from 1 to 4 days, followed by immediate drying, on subsequent germination in the field. Rows almost destitute of plants are invariably check or untreated rows, whereas the best rows consistently were planted with seed soaked 2 days or longer. Only 100 burs were planted to a row. Planted May 15 and photographed August 3.

sponse of any of the plantings for the pretreated and the lowest for the untreated seed. In this planting the best preseeding treatment, soaking 72 hours, gave a bur germination of 46.6% as compared to 7.0% for the untreated seed. The better germination of the untreated seed in the first two plantings is believed to have been the result of climatic conditions prevailing immediately after seeding. That is, the soil was moist at seeding time or shortly thereafter but only for a short time, thereby simulating in effect the actual soaking and drying treatments. The same conditions are believed to have lowered the germination of the treated samples, because they would tend to encourage immediate germination of the more quickly responding material, only to result in pre-emergence mortality as a result of desiccation of the tender insufficiently rooted seedlings.

TABLE 2.—*Germination results obtained from field plantings of soaked and unsoaked buffalo grass seed at Hays, Kansas.*

Planting date	Replication row	Percentage bur germination by soaking treatments					Average germination, %
		None	24 hours	48 hours	72 hours	96 hours	
April 13, 1940	1st	7	29	37	32	27	
	2nd	15	28	32	36	29	
	3rd	22	24	33	33	28	
	4th	14	30	29	39	25	
	5th	10	23	40	25	38	
	6th	9	20	27	33	28	
	7th	14	17	29	37	30	
	Average	13.0	24.4	32.4	33.6	29.3	26.5
April 29, 1940	1st	11	20	26	31	30	
	2nd	19	24	20	39	40	
	3rd	14	29	29	27	31	
	4th	18	32	36	25	43	
	5th	17	27	46	29	38	
	6th	16	29	42	35	38	
	7th	13	30	42	33	40	
	Average	15.4	27.3	34.4	31.3	37.0	29.1
May 15, 1940	1st	14	45	49	44	52	
	2nd	5	31	37	59	40	
	3rd	5	29	55	40	37	
	4th	9	36	40	40	38	
	5th	5	22	37	51	33	
	6th	5	23	46	37	41	
	7th	6	29	47	55	37	
	Average	7.0	30.7	44.4	46.6	39.7	33.7
Grand average...		11.8	27.5	37.1	37.1	35.3	29.8

Field counts of each planting were made at intervals of approximately 2 weeks. These counts showed that about 70% of the total emergence of the April 13 planting took place during the first 30 days.

The remaining 30% emerged during the next 30 days. Slightly over 80% of the April 29 planting emerged during the first 30 days, but it required only 2 weeks for the remainder to emerge. In the May 15 planting, which was followed by optimum climatic conditions, 86% of the emergence took place during the first 2 weeks and the remainder during the ensuing 2 weeks.

The effect of soaking on longevity of the seed in storage is of primary concern. It would be expected that the untreated seed should increase in germination while the soaked seed would probably decrease. In lieu of actual results from this test, another test of similar nature is cited. In April 1938, buffalo grass seed 2 years of age was soaked in tap water for 72 hours then thoroughly dried and stored under laboratory conditions for 22 months. In February 1940, samples of the soaked and unsoaked seed were germinated in soil in the greenhouse. The soaked seed germinated 61.0% compared to 48.7% for the unsoaked seed on a viable caryopsis basis, thus indicating that the beneficial effects of soaking may be expected to continue for at least 2 years.

LABORATORY RESULTS IN 1940

Samples of all treated and untreated seed were submitted to the Division of Forage Crops and Diseases for testing under laboratory conditions. Laboratory tests were started April 13. The seed was put to germinate in petri dishes on paper toweling moistened with water and with a 0.2% solution of potassium nitrate, at alternating temperatures of room (approximately 20°C) for 17 hours, with no special effort to exclude all light, and 35°C for 7 hours in a dark germination chamber. Previous laboratory tests showed that the results on paper toweling moistened with 0.2% potassium nitrate were comparable to tests made in soil. For the other tests, portions of each lot of seed were stored in paper bags and on moist paper toweling in petri dishes for 6 weeks at 5°C. At the end of the 6 weeks the samples were put to germinate at the alternating temperatures of room to 35°C.

The same response was obtained in laboratory tests from soaking as was obtained in the field, except all figures were slightly higher as would be expected. The results of the laboratory tests are presented in Table 3.

Prechilling in a dry state materially increased the germination of all treated and untreated seed, which is consistent with the work of Pladeck (1) and others. Prechilling in a moist state gave still better germination than prechilling dry in the case of untreated seed. In this instance it was observed that germination began within 24 hours and was completed within 5 days, whereas in the other tests from 14 to 21 days were required for completion of the germination. It was further observed that in the case of soaked seed regardless of whether it was chilled or not, the samples soaked as long as 48 hours gave maximum germination in 5 days and nearly complete germination within 14 days. Similar observations were made both in the greenhouse and under field conditions at Hays.

TABLE 3.—*Germination results obtained from laboratory tests (room to 35° C) of soaked and unsoaked buffalo grass seed with and without a period of prechilling (5° C).*

Principal soaking treatment	Subsequent laboratory treatment	% germination of viable burs		% germination of sound caryopses	
		Water	Potassium nitrate	Water	Potassium nitrate
None	None	8.6	33.0	3.5	15.7
	Prechilled moist 6 wks.*	70.8	97.8	48.2	88.9
	Prechilled dry 6 wks.	27.7	56.5	14.7	36.6
24 hours	None	47.1	77.4	27.2	40.8
	Prechilled dry 6 wks.	66.7	80.2	41.3	51.4
48 hours	None	61.5	66.3	37.7	40.0
	Prechilled dry 6 wks.	75.6	89.9	53.8	73.6
72 hours	None	62.8	88.0	40.2	55.4
	Prechilled dry 6 wks.	86.8	89.7	60.8	70.5
96 hours	None	54.2	85.6	35.0	58.9
	Prechilled dry 6 wks.	78.9	87.2	57.9	64.9

*Prechilling accomplished in petri dishes on paper toweling moistened with either water or potassium nitrate solution as indicated by subsequent germination method.

SUMMARY AND CONCLUSIONS

Soaking in water for 2 to 4 days followed by immediate and thorough drying as a preseeding treatment appears practical in overcoming the delayed germination and dormancy of buffalo grass seed. Age of seed and stage of maturity at harvest are important in determining the proper length of time to soak. In general, the older the seed and the longer it has been weathered, the shorter should be the soaking period.

Planting 2-year old seed soaked for 2 to 4 days, as described, resulted in an average field germination of 33.0% under adverse conditions as compared to 14.2% for untreated seed. Under optimum conditions the same treatments gave an average field germination of 43.6% as compared to 7.0% for untreated seed.

In the laboratory, the same seed from the 48-, 72-, and 96-hour treatments gave an average bur germination of 59.5% and 80.0% by the water and potassium nitrate methods, respectively, as compared to 8.6% and 33.0% for untreated seed. On a caryopsis basis the soaking treatments gave an average germination of 37.6% and 51.4% as compared to 3.5% and 15.7% for untreated seed by the same respective laboratory methods.

In addition to improving the germination, the emergence of the treated seed was decidedly more prompt and uniform under both field and laboratory conditions in this test and under greenhouse

conditions in another test of a similar nature. In most cases quick uniform germination is believed to be a decided advantage in establishing stands.

Prechilling the seed dry, either treated or untreated, for 6 weeks at 5°C gave significant increases in germination. In the case of seed which had been soaked, the effect of prechilling can best be seen with germination expressed on a caryopsis basis, because the seed contained on an average slightly more than two caryopses per bur.

From an earlier test, it was determined that soaked buffalo grass seed will retain its viability very well for at least 2 years after soaking. At the conclusion of the present experiment, more information on longevity and the normal germination trends of treated and untreated seed should be available. This information will be needed in determining whether commercial lots of seed can be soaked in advance of sale without danger of loss from spoilage when carried over.

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CUTTING TREATMENTS AS AN AID IN THE APPRAISAL OF VARIETIES OF ALFALFA[1]

DALE SMITH AND L. F. GRABER[2]

OBVIOUSLY, varietal appraisals of alfalfa require measurements of adaptability to a wide range of environmental conditions. Like all perennials, this plant is exposed to the extremes of the environmental variability of a locality, not only for a season or a year, but for several years. It is the degrees of adversity in such periods and the frequency of their occurrence which determine the magnitude of the differentials in varietal responses and the immediacy of their expression. Survival is the general characteristic which is most directly associated with differences in the productivity of varieties and strains which are, or promise to be, of commercial significance. This is true in Wisconsin and other regions where the problems of winter injury and bacterial wilt disease are serious. But even in these regions significant differentials in the responses of varieties and of strains may not occur for periods of from 3 to 6 years unless the internal environment is modified by cutting treatments.

This paper reports evidence of a preliminary character to show that cutting schedules may serve to hasten as well as to amplify the evaluation of alfalfas. The data are derived from trials conducted several years ago and from trials begun in 1938 on uniform plots of several varieties which at that time were 5 years old. The plot designs were not such as to lend themselves readily to statistical analysis and only where the contrasts were pronounced were they regarded as being significant in these preliminary trials.

VARIETAL RESPONSES DURING 1920 TO 1925

In a 5-year trial, Graber, *et. al.* (1)[3] found that the yields of Grimm and Kansas Common alfalfa sown in 1920 and cut twice annually (1921–25) at deferred stages of growth averaged 3.26 tons and 3.24 tons, respectively, of oven-dried, weed-free hay per acre, per annum. However, when cut three times annually at earlier stages of growth, Grimm produced 2.44 tons of hay per acre and Kansas Common only 1.91 tons per acre as an average for the 5-year period. Kansas Common produced the same yield as commercially imported Turkistan (an annual average of 1.91 tons of hay per acre) when cut three times annually for the 5-year period, but with two deferred cuttings the productivity of the Kansas Common was 3.24 tons per acre and that of Turkistan only 2.42 tons. In this trial, varietal differences in yields were dependent primarily on variations in cutting treatments.

Such results are much in contrast with those obtained in another series of plots, 40 rods distant, which were sown to several strains of

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[2]Research Assistant and Professor of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 152.

Grimm, Cossack, Common, and Imported Turkistan in 1921. The soil was similar, but topographically its exposure to the winter hazards of alfalfa was much greater. The stands in all plots were uniformly good in the fall of 1921 but severe winter killing (Table 1) occurred with the less hardy varieties and strains during the ensuing winter of 1921–22. The populations of 37 strains of Grimm and of 10 strains of Cossack were reduced 10.1 and 9.4%, respectively, whereas 15 strains of the Utah Common, 8 strains of Idaho Common, 10 strains of Kansas Common, 13 strains of Montana Common, and 13 strains of South Dakota Common were reduced 81.8, 76.8, 74.1, 68.8, and 56.6%, respectively, during the winter of 1921–22. Commercially imported Turkistan winterkilled 27.8%. Subsequent losses from winter injury were small with all strains and bacterial wilt disease was not a serious factor in survival or yields.

TABLE 1.—*Differences in winterkilling and in yields of varieties and strains of alfalfa sown in 1921.*

Variety	No. of strains*	Origin	Winter loss 1921–22, %	Tons per acre, av. 1922, 1923, and 1924
Grimm	37	Mont., Ida., and N. & S. Dak.	10.1	2.84
Cossack	10	S. Dak.	9.4	2.70
Common	10	Kan.	74.1	1.81
Common	13	S. Dak.	56.6	1.58
Common	13	Mont.	68.8	1.51
Common	8	Ida.	76.8	1.23
Common	15	Utah	81.8	0.53
Imported Turkistan	9	Commercial	27.8	1.50

*Unless otherwise indicated, the term strains refers to alfalfa seed obtained from growers in the states mentioned.

All varieties and strains were cut twice annually at, or near, the full-bloom stage for the seasons of 1922, 1923, and 1924. The 37 strains of Grimm were remarkably uniform in production. They averaged a ton or more of weed-free, oven-dried hay per acre in excess of any of the regional strains of Common. The strains of Utah Common averaged 81, Idaho 57, Montana 47, South Dakota 44, and Kansas 36% less in yield than Grimm. Cossack was close to Grimm in productivity but Turkistan yielded 47% less. Differences between the average yields of the strains of Common from Kansas, South Dakota, and Montana were not regarded as being significant. The strains of commercially imported Turkistan had fairly good survival. They were typically dormant in the autumnal stages of growth and very susceptible to foliar diseases. A rapid ingress of bluegrass occurred in these plots. With the exception of Turkistan, the major differences in

yields were due to differences in winterkilling which occurred in 1921–22 before the alfalfa was cut for hay.

These results are presented to illustrate that significant varietal responses to the environment may appear prominently before cutting treatments are begun and before yields are expressed. However, climatic conditions unfavorable for survival of moderately hardy varieties do not usually occur immediately following the establishment of a varietial trial. Graber (2) has shown that well-established new seedings of alfalfa are far more resistant to the stress of unfavorable winters in Wisconsin than are stands of the same varieties two years old or older. Moreover, it is well known that bacterial wilt disease is usually not a factor in the duration of alfalfa until after fields are two or more years old and this is true especially in dry periods. Such circumstances may require several years for the expression of noteworthy differences in important varietal characteristics of alfalfa unless the internal environment is adjusted to various levels by selective cutting schedules. Such cutting schedules do not alter climatic aspects of the external environment, but they may enhance varietal appraisals by intensifying the interactions of the factors of the external environment with those of the internal environment.

SPRING CLIPPING AS AN AID IN EVALUATION

Spring clipping of alfalfa was employed in 1938 on seven varieties known to vary greatly in their tolerance to bacterial wilt disease and winter injury. The area selected for this trial was a portion of a series of 5-year-old plots which had been seeded on May 15, 1933. The soil was wilt infested and was of moderate water-holding capacity. From 1934 to 1937, inclusive, the alfalfa had been given two deferred cuttings annually and a good uniform stand prevailed in the spring of 1938 in all of the plots. Dry weather had probably been a factor in retarding losses in survival from bacterial wilt.

The seven varieties of alfalfa were as follows: Four plots of Common, consisting of one strain from Minnesota and one each from South Dakota, Ohio, and Idaho; two plots each of Hardistan, Turkistan, and Ladak; and one plot each of Cossack, Grimm, and Hardigan. Each of the 13 plots was divided into 4 equal areas, 1/275 acre in size, in such a manner as to provide a total of 52 plots for three cutting treatments of each variety or strain. In one of these cutting treatments (B) the plots were in duplicate.

The cutting treatments (Table 2) applied to the seven varieties of alfalfa during the growing season of 1938 were as follows: One set of 13 plots was given two deferred summer cuttings with a field mower at a level of about 1 inch above the crowns on June 22 and July 27 when the alfalfa was near full bloom. This treatment is designated as A. It was the same cutting treatment which the entire field had received previously. Two sets of 13 plots were clipped with a field mower (treatment B) on April 29 to a level of 1 inch above the crowns when the top growth was 4 inches high. The alfalfa was then allowed to recover and two summer cuttings were made on July 5 and August 26 when the plants were in full bloom. The remaining set of 13 plots was

clipped twice in the spring (treatment C), on April 29 and May 20, at the same level. Each clipping was made when the top growth was 4 inches high and was followed by two summer cuttings when the plants were beginning to bloom on July 5 and again on August 26.

The cutting treatments were continued during 1939 (Table 3) on the same plots with some variation in the schedules A, B, and C. The set of 13 plots of alfalfa which had been weakened by two spring clippings followed by two summer cuttings in 1938 (treatment C) was given only two deferred cuttings in 1939. These cuttings were made on the same dates (June 22 and August 23) as those of schedule A, and a comparison of the results of the two treatments, A and C, in 1939 shows the residual effects of the two clippings of the previous season. Cutting treatment B was continued on two sets of plots as in 1938, except that rains during the latter part of April delayed the spring clipping until May 13, 1939, when the alfalfa was fully 6 inches high. This reduced the food reserves to a very low level and such deferment of spring clipping delayed the two subsequent summer cuttings to July 7 and August 23 at which time the yields were very low. All yields in 1938 and 1939 were calculated in pounds per acre of weed-free, oven-dried hay.

The stand of alfalfa in each of the 52 plots was measured by plant counts made with the aid of a wooden quadrat having an inside area of 2 square feet. The quadrat was thrown at random five times in each plot and the number of plants enclosed by it were counted and recorded. The average of the five counts was taken as a basis for the population of alfalfa plants occurring in each plot during the period of the trial.

VARIETAL DIFFERENCES IN YIELDS AS AFFECTED BY SPRING CLIPPINGS IN 1938

A summary of the yield data for 1938 is tabulated in Table 2. When the 5-year-old alfalfa was given two deferred summer cuttings (A), the total yields were very much larger than the total yields of the alfalfa clipped either once (B) or twice (C) in the spring at short immature stages of growth and then followed by two summer cuttings. Treatment C reduced the yields from 61.4 to 74.0% below those obtained with treatment A, while with treatment B such reductions were only from 7.3 to 19.6%. There was not much differentiation in varietal responses to the three cutting treatments A, B, and C on the basis of total yields in 1938. However, the very wilt-susceptible varieties Hardigan, Grimm, and Common showed a marked decline in the last cutting on August 26 under the extreme severity of treatment C. Although the productivity of all the alfalfa was very low on August 26, yields of 14.7, 34.1, and 26.9 pounds per acre for Grimm, Common, and Hardigan, respectively, are contrasting when compared with yields of 124.8, 88.4, 137.2, and 126.1 pounds per acre for Hardistan, Turkistan, Ladak, and Cossack, respectively. Such varietal responses were due largely to differences in survival, as will be seen later.

TABLE 2.—*Average yields and percentages of reduction in the 1938 yields of seven varieties of 5-year-old alfalfa as affected by cutting treatments.*

Variety and treatment*	No. of plats in each treatment	Yield of oven-dry alfalfa in pounds per acre, 1938							Reduction in total yield, %
		Apr. 29	May 20	June 22	July 5	July 27	Aug. 26	Total	
Hardistan A	2			2,715.4		1,590.5		4,305.9	
B	4	617.7			2,589.8		782.5	3,990.0	7.3
C	2	620.6	368.8		548.3		124.8	1,662.5	61.4
Turkistan A	2			2,607.2		1,549.9		4,157.1	
B	4	641.8			2,356.9		744.8	3,743.5	10.0
C	2	624.6	311.1		524.5		88.4	1,548.6	62.8
Ladak A	2			3,115.0		1,646.9		4,761.9	
B	4	683.3			2,495.3		771.7	3,950.3	17.0
C	2	621.0	371.0		583.9		137.2	1,713.1	64.0
Cossack A	1			2,902.5		1,536.3		4,438.8	
B	2	502.9			2,366.3		701.3	3,570.5	19.6
C	1	487.6	410.8		306.3		126.1	1,330.8	70.0
Grimm A	1			2,783.2		1,664.8		4,448.0	
B	2	600.1			2,650.1		856.5	4,106.7	7.7
C	1	548.6	406.7		444.3		14.7	1,414.3	68.2
Common A	4			2,752.5		1,642.6		4,395.1	
B	8	577.4			2.466.6		823.1	3,867.1	12.0
C	4	416.5	305.8		388.5		34.1	1,144.9	74.0
Hardigan A	1			2,882.6		1,631.0		4,513.6	
B	2	651.6			2,527.5		852.3	4,031.4	10.7
C	1	544.8	406.2		349.0		26.9	1,326.9	70.6

*A = Continuation of two deferred summer cuttings; B = One spring clipping followed by two summer cuttings in 1938 and 1939; and C = Two spring clippings followed by two summer cuttings in 1938 and two deferred summer cuttings in 1939.

PRODUCTIVITY IN 1939

Rainfall was very deficient in 1939 and this probably influenced the current as well as the residual effects of the cutting treatments. On the basis of total yields (Table 3) of alfalfa hay from two deferred summer cuttings (A), the residual effects of two spring clippings in the previous year (C) is shown by reductions in productivity which ranged from 46.2 to 95.9%, while the reductions resulting from the continuation of one spring clipping (B) were 44.3 to 68.3%.

TABLE 3.—*Average yields and percentages of reduction in the yields from cuttings in 1939 of seven varieties of 6-year-old alfalfa.*

Variety and treatment*	No. of plots in each treatment	Yield of oven-dry alfalfa in pounds per acre, 1939					Reduction in total yields, %
		May 13	June 22	July 7	Aug. 23	Total	
Hardistan A	2		1,608.8		562.2	2,171.0	
B	4	229.2		674.5	305.6	1,209.3	44.3
C	2		692.9		477.8	1,170.7	46.2
Turkistan A	2		1,437.5		594.9	2,032.4	
B	4	152.4		640.5	300.8	1,093.7	46.2
C	2		452.0		325.3	777.3	61.8
Ladak A	2		2,511.6		563.5	3,075.1	
B	4	184.7		741.2	221.9	1,147.8	62.7
C	2		579.9		334.9	914.8	70.3
Cossack A	1		1,628.1		383.9	2,012.0	
B	2	143.2		345.8	148.4	637.4	68.3
C	1		111.6		133.4	245.0	87.8
Grimm A	1		1,502.8		402.9	1,905.7	
B	2	150.8		428.8	136.2	715.8	62.4
C	1		19.1		70.8	89.9	95.3
Common A	4		1,713.8		616.0	2,329.8	
B	8	124.8		451.3	197.7	773.8	66.8
C	4		70.8		107.6	178.4	92.3
Hardigan A	1		1,470.2		364.8	1,835.0	
B	2	126.1		454.7	142.9	723.7	60.6
C	1		74.6		0.0	74.6	95.9

*A = Continuation of two deferred summer cuttings; B = One spring clipping followed by two summer cuttings in 1938 and 1939; and C = Two spring clippings followed by two summer cuttings in 1938 and two deferred summer cuttings in 1939.

Varietal differentiations in yields were very apparent under cutting treatments C and B, but with the exception of Ladak, they were not prominent with the continuation of the two deferred summer cuttings (A) even after 6 years of such treatment. Under treatment C the yields on June 22 of the relatively hardy and wilt-tolerant varieties Hardistan, Turkistan, and Ladak were 692.9, 452.0, and 579.9 pounds of oven-dried, weed-free hay per acre, respectively, compared with only 74.6, 19.1, 70.8, and 111.6 pounds, respectively, for the wilt-susceptible varieties Hardigan, Grimm, Common, and Cossack.

On August 23, 1939, varietal differences with treatment C were much more pronounced. Hardistan, Turkistan, and Ladak yielded 477.8, 325.3, and 334.9 pounds, respectively, in contrast to Hardigan, 0.0 pound; Grimm, 70.8 pounds; Common, 107.6 pounds; and Cossack, 133.4 pounds.

Varietal differences were not as pronounced under treatment B, but they appeared in the cuttings on July 7 and on August 23. The wilt-susceptible varieties Hardigan, Grimm, Common, and Cossack averaged 420.2 pounds per acre of alfalfa hay from the cutting on July 7 and 156.3 pounds per acre at the final cutting, while the wilt-tolerant varieties averaged 685.4 and 276.1 pounds per acre, respectively, with the same cuttings.

VARIETAL DIFFERENCES IN STAND

The survival of commercial and other varieties and strains of alfalfa, including those utilized in these trials, is well known, having been ascertained with respect to bacterial wilt disease and winter injury in artificial tests as well as those conducted under field conditions. Jones (5) reports provisional estimates of wilt resistance on the basis of artificial inoculations and for the purpose of comparison, as follows: "Peruvian alfalfa, Grimm, Hardigan, and the common varieties contain very few resistant plants, usually less than 1%, though local strains believed to be derived from Turkistan alfalfa or with some admixture from this source, have more. Cossack alfalfa usually has less than 10% of resistant plants. In Ladak about a third of the plants usually appear highly resistant, while in Hardistan and Orestan and other more resistant strains from Turkistan importations, about half of the plants may be so classed. The results of these comparatively rapid artificial tests of alfalfa varieties have been an aid in predicting the outcome of longtime field trials. It is from field trials that the value of varieties in avoiding loss from this disease must be determined."

Similar results have been obtained by Peltier and Tysdal (6) on the basis of artificial inoculations, while Salmon (7), and Graber and Jones (4) give further evidence on the field survival of varieties and strains of alfalfa with respect to bacterial wilt disease. The evaluation of the winter resistance of varieties of alfalfa have been made by most states where winter injury is a problem in alfalfa culture.

The changes which took place in the stands of the seven varieties under trial during 1938 and 1939 are given in Table 4. They are in accord with the generally recognized performance of these varieties. At the beginning of the experiment in the spring of 1938, the plant populations were similar, averaging about 19.5 plants per 2 square feet, and the stands were relatively uniform. The populations of the wilt-susceptible varieties were reduced much more rapidly under treatment C than with B or A but marked varietal differences prevailed on May 6, 1939, with all cutting treatments.

On the basis of the original stands (April 18, 1938), Hardistan, Ladak, and Turkistan were reduced 69.3, 69.2, and 62.6%, respectively, by May 6, 1939, under treatment C, but Hardigan was com-

pletely eliminated and only a few scattered plants of Grimm remained. The stands of Common and Cossack were reduced 86.1 and 83.1%, respectively.

TABLE 4.—*The average number of alfalfa plants per 2 square feet and the percentage reduction in the stand of three wilt-tolerant and four wilt-susceptible varieties of 5-year-old alfalfa as affected by the cutting treatments made in 1938 and 1939.*

Variety	Cutting treatments*	Plant counts			Percentage reduction in populations on	
		Apr. 18, 1939	May 6, 1939	Apr. 27, 1940	May 6, 1939	Apr. 27, 1940
		Wilt-tolerant varieties				
Hardistan	A	19.3	16.9	8.5	12.4	56.0
	B	20.3	10.5	4.9	48.3	75.9
	C	20.5	6.3	3.8	69.3	81.5
Turkistan	A	20.5	14.9	9.5	27.3	53.7
	B	19.1	9.8	4.3	48.7	77.5
	C	20.3	7.6	4.0	62.6	80.3
Ladak	A	20.5	16.6	9.5	19.0	53.7
	B	19.5	8.7	3.4	55.4	82.6
	C	18.5	5.7	3.1	69.2	83.2
		Wilt-susceptible varieties				
Cossack†	A	19.0	8.7	4.5	54.2	76.3
	B	16.5	5.1	0.9	69.1	94.5
	C	16.0	2.7	1.3	83.1	91.9
Grimm	A	19.5	9.7	7.0	50.3	64.1
	B	19.3	5.0	1.4	74.1	92.7
	C	23.0	0.0‡	0.0	100.0	100.0
Common	A	18.3	11.1	6.2	39.3	66.1
	B	17.8	7.0	2.8	60.7	84.3
	C	16.5	2.3	0.9	86.1	94.5
Hardigan	A	22.0	9.0	4.3	59.1	80.5
	B	26.3	8.1	1.8	69.2	93.2
	C	19.0	0.0	0.0	100.0	100.0

*A = Continuation of two deferred summer cuttings; B = One spring clipping followed by two summer cuttings in 1938 and 1939; and C = Two spring clipping followed by two summer cuttings in 1938; two deferred summer cuttings in 1939.

†Ordinarily, in wilt-infested fields, Cossack maintains a satisfactory stand of alfalfa from 1 to 2 years longer than the wilt-susceptible varieties Hardigan, Grimm, and Common, but since Hardistan, Turkistan, and Ladak have a much superior field tolerance to bacterial wilt, Cossack has been grouped with the susceptible varieties.

‡Although a total loss of plants is indicated, a few scattered plants remained. They were missed in the randomized counts.

With treatment B, the reductions in stands of Hardistan, Ladak, and Turkistan on May 6, 1939, were 48.3, 55.4, and 48.7%, respectively, as compared with Hardigan, 69.2%; Grimm, 74.1%; Common, 60.7%; and Cossack, 69.1%.

Differences in the reductions of stands on May 6, 1939, were also very pronounced under treatment A. Hardistan, Ladak, and Turki-

stan were reduced 12.4, 19.0, and 27.3%, respectively, while Hardigan, Grimm, Common, and Cossack were reduced 59.1, 50.3, 39.3, and 54.2%, respectively. However, such differences in survival did not materially affect the yields of the varieties on June 22 or August 26, since stands that are moderately thin are, at times, more productive in dry seasons than are thick stands.

Reductions in the populations, on the basis of the original stands on April 18, 1938, continued to prevail in 1940 as shown by counts on April 27. With treatment C, the plant populations were 83.2, 81.5, and 80.3% less than the original populations of Ladak, Hardistan, and Turkistan, respectively, while losses of 100.0, 100.0, 94.5, and 91.9% occurred in Hardigan, Grimm, Common, and Cossack, respectively.

On April 27, 1940, the stands of Ladak under treatment B were reduced 82.6%, those of Turkistan 77.5%, and of Hardistan 75.9% as compared with Hardigan, 93.2%; Grimm, 92.7%; Common, 84.3%; and Cossack, 94.5%. With treatment A, the reductions in stands were 53.7, 56.0, and 53.7% for Ladak, Hardistan, and Turkistan, respectively, as compared with 80.5, 64.1, 66.1, and 76.3% for Hardigan, Grimm, Common, and Cossack, respectively.

Bacterial wilt disease was the principal factor in the differentiations in survival and yields. Although this was not ascertained by actual determinations, observations of wilt symptoms in the plats with respect to varieties and cutting treatments verified this assertion. Often it is very difficult to distinguish losses in plant populations that are due to wilt primarily from those that are due to winter injury or other destructive and associated factors. However, in this trial the indirect evidence was fairly positive that wilt was the dominant factor in the varietal responses which prevailed. It is known that the very wilt-susceptible varieties Hardigan and Grimm possess a degree of winter-hardiness similar to that of the wilt-tolerant varieties Hardistan and Ladak. In this trial, the former sustained much greater losses in stand and in yields than did the latter varieties under treatment C. Likewise, Hardigan is known to be more susceptible to wilt disease than the equally hardy Grimm. This differential is also expressed in the data on yields under treatment C. Moreover, Cossack, with two deferred cuttings, will usually maintain a productive stand for one or two years longer than Grimm when both are grown on wilt-infested soil. The superiority of Cossack in survival and yields over Grimm and Hardigan was clearly expressed in the plats and in the data obtained under treatment C. Such evidence in this trial is not only convincing with respect to the dominance of bacterial wilt disease as a differentiating factor in survival, but it lends support to the belief that spring clippings, such as were employed in treatment C, will hasten and amplify differences in the responses of varieties to the disease.

DISCUSSION

Alfalfa is very sensitive to cutting treatments in Wisconsin. Graber and Sprague (3) have shown that the total yields of oven-dried hay per acre for a period of 4 years (1931–34) from hardy Canadian variegated alfalfa grown on a very fertile Miami silt loam soil ranged from

9.07 tons to 13.29 tons per acre with six different cutting treatments, none of which were far removed from those employed in farm practice. With the same cutting treatments, but with only moderate soil fertility, the range in productivity of Canadian variegated alfalfa was 5.98 to 9.14 tons per acre. In all cases, survival declined rapidly under unfavorable managerial treatments. Such marked responses of a hardy variety suggest the plausibility of utilizing supplementary cutting treatments as an aid in the appraisal of varieties and strains of alfalfa and the data presented in this paper give support to this concept.

It is not meant to imply from preliminary results that spring clippings or other supplementary cutting schedules are absolute requirements for varietal appraisals of alfalfa. At best, they may only serve to hasten evaluations and to amplify them, if and when, a particular schedule of cuttings is ascertained which will augment a given response. For example, if late fall cutting would increase winter injury it might be utilized to intensify varietal differentiations in this respect. Since spring clippings hastened eliminations by bacterial wilt, this treatment may serve to quicken the differential responses of wilt-tolerant and wilt-susceptible varieties and strains. Such cutting schedules along with two or more levels of soil fertility and the selection of trial areas with different degrees of exposure and drainage, provide a wide range in the environment for the expression of varietal responses. Moreover, the establishment of new varietal tests for two or three consecutive years in each trial area are helpful in agronomic appraisals of varieties and strains of alfalfa, since well-established new seedings are much more winterhardy than are stands of alfalfa two or more years old. Limitations of land area and labor may be objectionable features of these proposals and it is true that varietal numbers would need to be held to a minimum. However, most commercial varieties have been evaluated and a comparison of one or two of them with new varieties or strains is suggested as a means of avoiding over-expansion.

SUMMARY

Data are presented to show that significant differences in field responses of varieties and strains of alfalfa with varying degrees of winterhardiness and tolerance to bacterial wilt disease may not appear for periods of from 5 to 6 years when given a standard cutting treatment.

Cutting schedules which included spring clippings were not only detrimental to survival and the production of forage, but they hastened and amplified the differences in these major agronomic characteristics of wilt-tolerant and wilt-susceptible varieties of alfalfa.

Aside from cutting treatments, which may be standard for a given locality or region, other cutting schedules designed specifically to augment responses to bacterial wilt disease and to winter losses may prove very useful in appraising new varieties and strains of alfalfa.

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CALCIUM AS A FACTOR IN SEED GERMINATION[1]

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THAT the soil should be a factor in determining the percentage germination of seeds may seem an overemphasis of the soil's service in plant growth. When the ash content of a plant is approximately only 5% or, as a maximum, 10%, then this is a relatively small contribution by the soil. But when growth as a synthesis of carbon-dioxide and water into compounds by means of sunshine energy will occur only after the soil has made its seemingly small contribution, this diminutive offering mounts in its importance. Since the major part of the nutrients from the soil enter the plant in the early phases of its life history, it seemed logical to determine whether variation in soil fertility, particularly of calcium, might not register its effects so early in plant life as even to influence the percentage germination of the seeds of a crop like the tomato, for example, which is not commonly considered a calcophile.

PLAN OF EXPERIMENT

The tomato seeds were planted in ordinary greenhouse flats at increasing rates, starting with 14 seeds per row, or a spacing of 1 inch between the seeds, and increasing to 5, 10, 15, and 20 times this number per consecutive row. The rows and the rates were duplicated in the second half of the flat. The soil treatments used consisted of (a) none, (b) calcium chloride, (c) complete fertilizer, and (d) calcium chloride plus complete fertilizer. These treatments were duplicated by duplicate flats.

Three trials, each with a growth period of approximately 4 weeks, were carried out in February, March, and May, respectively. The soil treatments were mixed as chemicals and ground with fine quartz sand so as to provide sufficient bulk for uniform distribution by hand in the bottom of the rill. Water was sprinkled on the applied fertilizer, the flats were covered, and 3 or 4 days allowed before the respective seed numbers previously counted out were planted and covered. Observations of the early plant appearances were made and the growth with possible disease incidence studied. After 27 to 29 days the counts were made of the plants per row.

RESULTS

When the number of plants produced (Table 1) is considered in relation to the number of seeds planted, regardless of soil treatments, a decreasing germination with increased rate of seeding is clearly demonstrated. These data represent a combination of all the soil treatments with 12 cases in each growing period and 36 cases in the mean. The mean is expressed for the plants as percentage of the seeds planted and also as percentage, assuming the plants in the lowest

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seeding rate as representative of the viable seeds of the lot. The large decrease in number of emerging plants with the increased rate of seeding was observed in the counts of the individual rows as well as in the summation of the data.

TABLE 1.—*Plants produced and percentage germination represented thereby with increased rate of seeding.*

Seeds planted per row	February		March		May		Mean	
	Plants	%	Plants	%	Plants	%	% of seeds planted	%
14	6.6	47	7.7	55	9.3	66	56	100
70	21.3	30	22.5	32	41.6	59	40	70
140	21.0	15	30.5	21	69.1	49	28	48
210	13.7	6	34.7	16	89.6	42	21	35
280	21.7	7	40.8	14	93.8	33	16	30

These observations raise the question as to the soil condition responsible for the decrease in germination, when careful attention was given to such items as provision of ample moisture, as covering the planted flats with a thin surface layer of quartz sand, and other means of providing optimum conditions for germination. There is an improved germination with the advance in the season, but all three trials suggest that there is some soil factor which may be sufficient for the limited seed numbers but becomes insufficient for their increasing numbers.

That some soil factor, such as a nutrient element, is responsible herein is suggested when the same data are assembled to show the variable germination in relation to the different soil treatments, as presented in Table 2.

TABLE 2.—*Percentage germination as influenced by soil treatments.*

Seeds planted per row	No treatment		Calcium only		Complete fertilizer		Calcium and fertilizer	
	Plants	%	Plants	%	Plants	%	Plants	%
14	7.6	54	9.3	66	6.8	48	8.0	57
70	27.9	39	36.5	52	20.8	29	29.1	41
140	35.6	25	51.6	36	28.6	20	45.1	32
210	40.3	19	64.5	30	32.1	15	50.0	23
280	48.1	17	66.7	23	32.6	11	57.1	20

It is significant that the complete fertilizer applied and watered well into the soil for 3 days in advance of the seeding should give the lowest germination of all the trials. This fertilizer addition may be credited with an injurious effect, since the numbers fell below those for the soil without treatment. When the calcium, which was a chloride and not in an acid-neutralizing carbonate form, was added along with the fertilizer, it served to offset the injury. It improved

the germination beyond that in the untreated soil. This improvement was relatively greater as the seeding rate was larger. It was most startling, however, to find that the introduction into the soil of calcium chloride alone gave the highest percentage of plants from the seeds planted.

CONCLUSIONS

Such increases suggest a possible significance of calcium in the soil for better seed germination. Its effects can not be ascribed to changes in soil reaction. It must be related to the role of calcium as a nutrient, and gives the calcium of the soil an importance for possible attention in practice in terms of exceedingly small amounts for significant benefits.

FORAGE YIELDS OF FIVE VARIETIES OF ALFALFA GROWN IN NURSERY ROWS AND FIELD PLOTS[1]

RALPH M. WEIHING AND D. W. ROBERTSON[2]

IN the past few years there has been much interest in the use of nursery plots for estimating the yield of new strains of alfalfa. The large number of strains to test, and in many cases the small quantity of seed available, prohibit the use of field plots. The yields of five varieties from several types of nursery plots at the Colorado Experiment Station were compared with yields from 1/20 acre field plots. The data from this experiment are suggestive of types of nursery plots which give results comparable to field plots.

Tysdal and Kiesselbach[3] at the Nebraska Agricultural Experiment Station compared several types of nursery plots with field plots. From these studies and from their general experience with alfalfa nurseries, they recommend the following types of plots as most serviceable for advanced nursery testing: "(1) Solid-drilled 5 to 8 rows spaced 7 inches apart, with a 12- to 14-inch alley between border rows, or (2) solid-drilled 3 to 5 rows spaced 12 inches apart with an 18-inch alley between border rows." They also state, "Since removing border rows is difficult and expensive with this crop and since very little error has been found with such plots due to border effect, it is suggested that the entire plot may be harvested for yield, with the possible exception of removing border rows in case adjacent stands are decidedly different." They suggest that the rows be 16 feet or more in length and that the alley space be included in the plot area. "Single rows 18 to 24 inches apart are permissible for preliminary nursery testing."

ARRANGEMENT AND CARE OF EXPERIMENT

The five varieties Meeker Baltic, Grimm, Ladak, Nebraska Common, and Hardistan were seeded in the spring of 1938 at the rate of 10 pounds per acre in all types of plots. The seeding of field plots was with a standard grain drill and of the nursery rows by hand. Since the Latin Square design was used, five replications of each variety were necessary.

The field plots were 1/20 acre in size. In all cases the center 16 feet of the 18-foot nursery rows were harvested for yield. The five types of nursery plots were: (1) Single rows 3 feet apart, (2) single rows 20 inches apart, (3) three-row plots 20 inches between rows with 20-inch alleys, (4) three-row plots 12 inches between rows with 20-inch alleys, and (5) five-row plots 12 inches between rows with 20-inch alleys. Buffer rows were used when needed. Considering all possible single-row, three-row, and five-row yields, this experiment permits comparison of the

[1]Contribution from the Agronomy Section, Colorado Experiment Station. Published with the approval of the Director of the Colorado Experiment Station, Fort Collins, Colorado, as Scientific Series Paper No. 111. Also presented at the annual meeting of the Society, November 24, 1939, in New Orleans, Louisiana. Received for publication November 13, 1940.

[2]Assistant Agronomist and Agronomist, respectively.

[3]TYSDAL, H. M., and KIESSELBACH, T. A. Alfalfa nursery technic. Jour. Amer. Soc. Agron., 31:83–98. 1939.

five varieties in nine types of nursery plots with the field plots. The arrangement of part of the plots is shown in Fig. 1.

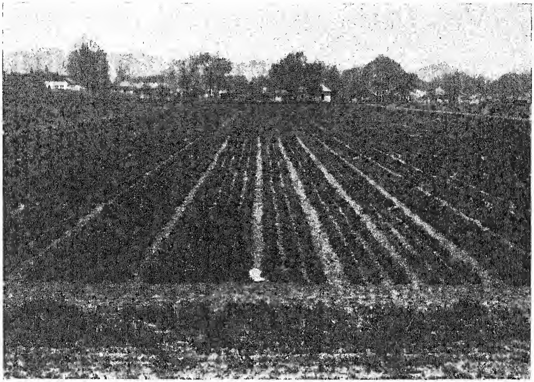

FIG. 1.—The three-row plots with 12 inches between rows and 20-inch alleys at right of the hat, and the five-row plots with 12 inches between rows and 20-inch alleys at left of the hat. The 1/20 acre field plots are in the background.

Because the nursery rows were kept free from weeds during the summer of 1938, the alfalfa made enough growth to permit one cutting that season. In 1939, all plots were harvested three times on the usual dates for cutting alfalfa in this area. All yields were computed in tons per acre on an oven-dry basis. The plot areas of the nursery rows were based on distance between rows so that part of the alley space was disregarded when it was wider than the distance between rows. The yield from each row was determined separately in order that the acre yield of the middle rows could be computed. In addition, the following combinations were made: The three rows of the three-row plots; and three middle rows and five rows of the five-row plots.

Each season the plots were irrigated three times, which was considered sufficient for normal growth.

YIELDS COMPARED

In 1938, the year of seeding, the nursery plots were cut once. The field plots with weed growth were not cut. The following season, three cuttings were obtained on all plots. The acre yields of nine types of nursery plots in 1938 and for field plots and nursery plots in 1939 are given in Table 1.

The yields in tons per acre of the five varieties in 1938 in the nine types of nursery plots ranked in order of high to low yields, were as follows: Ladak, 1.79; Meeker Baltic, 1.60; Grimm, 1.45; Nebraska Common, 1.34; and Hardistan, 1.31. In seven of the nine types, the ranking

TABLE 1.—*The yield in tons per acre of oven-dry hay of five varieties of alfalfa seeded in 1938 in field and nursery plots.*

Variety	1/20 acre field plots	Nursery plots									Average of all types of plots
		1-row plots 3 ft. apart	20-in. rows, 20-in. alleys			12-in. rows, 20-in. alleys					
			1-row plots	3-row plots		3-row plots		5-row plots			
				Middle row	3 rows	Middle row	3 rows	Middle row	Middle 3 rows	5 rows	
1938, Only One Cutting											
Ladak	—	1.23	1.72	1.68	1.69	1.95	2.13	1.79	1.92	2.03	1.79
Meeker Baltic	—	1.10	1.49	1.47	1.49	1.76	1.96	1.62	1.69	1.79	1.60
Grimm	—	0.99	1.40	1.36	1.33	1.64	1.74	1.54	1.49	1.57	1.45
Nebr. Common	—	0.93	1.26	1.30	1.25	1.44	1.59	1.33	1.45	1.54	1.34
Hardistan	—	0.84	1.24	1.22	1.22	1.43	1.60	1.38	1.37	1.51	1.31
2 S.E.diff.	—	0.05	0.08	0.12	0.12	0.14	0.10	0.16	0.11	0.06	0.03
First Cutting, 1939											
Ladak	2.95	2.59	2.67	3.00	2.91	3.34	3.73	3.11	3.32	3.56	3.12
Meeker Baltic	2.62	2.15	2.88	2.62	2.63	3.04	3.69	3.04	3.24	3.59	2.95
Grimm	2.42	2.07	2.41	2.44	2.39	2.79	3.33	2.95	2.81	3.14	2.67
Nebr. Common	2.27	1.97	2.28	2.28	2.35	2.66	3.24	2.60	2.77	3.17	2.56
Hardistan	2.28	1.80	2.22	2.16	2.25	2.30	2.84	2.70	2.64	3.00	2.42
2 S.E.diff.	0.15	0.10	0.25	0.19	0.18	0.17	0.26	0.49	0.36	0.33	0.08

Second Cutting, 1939											
Nebr. Common.	1.76	1.24	1.73	1.65	1.73	1.82	2.30	1.71	1.83	2.13	1.79
Grimm	1.70	1.23	1.62	1.61	1.67	1.76	2.18	1.90	1.83	2.07	1.76
Meeker Baltic	1.76	1.25	1.67	1.61	1.70	1.75	2.17	1.74	1.83	2.04	1.75
Hardistan	1.57	1.02	1.42	1.51	1.52	1.49	1.94	1.69	1.65	1.86	1.57
Ladak	1.48	0.91	1.01	1.21	1.22	1.39	1.57	1.42	1.44	1.59	1.32
2 S.E.diff.	0.16	0.08	0.12	0.09	0.05	0.09	0.12	0.16	0.10	0.08	0.04
Third Cutting, 1939											
Nebr. Common.	1.48	1.24	1.50	1.42	1.49	1.43	1.86	1.28	1.34	1.59	1.46
Meeker Baltic	1.40	1.10	1.42	1.33	1.38	1.33	1.63	1.29	1.31	1.47	1.37
Grimm	1.28	1.11	1.36	1.33	1.37	1.29	1.61	1.35	1.29	1.45	1.34
Hardistan	1.32	1.01	1.24	1.24	1.26	1.20	1.54	1.21	1.18	1.35	1.26
Ladak	0.85	0.80	0.78	0.99	0.97	1.04	1.12	1.02	1.04	1.11	0.97
2 S.E.diff.	0.13	0.09	0.12	0.09	0.06	0.12	0.09	0.13	0.08	0.09	0.03
Total Yield, 1939											
Meeker Baltic	5.78	4.50	5.97	5.56	5.72	6.13	7.49	6.07	6.38	7.10	6.07
Nebr. Common.	5.51	4.45	5.51	5.36	5.57	5.91	7.40	5.60	5.95	6.89	5.82
Grimm	5.41	4.41	5.39	5.38	5.42	5.83	7.12	6.19	5.93	6.67	5.77
Ladak	5.28	4.30	4.46	5.21	5.10	5.76	6.42	5.54	5.80	6.26	5.41
Hardistan	5.17	3.83	4.87	4.91	5.03	4.99	6.32	5.60	5.47	6.21	5.24
2 S.E.diff.	0.30	0.16	0.44	0.31	0.18	0.35	0.35	0.53	0.37	0.32	0.11

was the same. In the other two types, Hardistan exceeded Nebraska Common by 0.01 ton when all the rows in the three-row plots with 12 inches between rows were combined, and by 0.05 ton in the middle row of the five-row plots.

The yields in tons per acre of the five varieties in the season of 1939, ranked in the order of high to low yields for the 10 types of plots, were as follows: Meeker Baltic, 6.07; Nebraska Common, 5.82; Grimm, 5.77; Ladak, 5.41; and Hardistan, 5.24. While this order was changed in 3 of the 10 types of plots, only one of these changes seems to be of importance. The order of rank for the middle row of the five-row plots was changed to Grimm, 6.19; Meeker Baltic, 6.07; Nebraska Common, 5.60; Hardistan, 5.60; and Ladak, 5.54. The other changes, although small in comparison with 2 $S.E._{diff.}$ in those experiments, were as follows: (1) Ladak and Hardistan exchanged positions 4 and 5 on a difference of 0.41 ton in single rows spaced 20 inches apart, and (2) Nebraska Common and Grimm exchanged positions 2 and 3 on a difference of 0.02 ton in the middle row of the three-row plots spaced 20 inches between rows.

The rank of varieties for the various types of plots for the first, second, and third cutting yields was also nearly constant (Table 1). For the first cutting the order of varieties was Ladak, Meeker Baltic, Grimm, Nebraska Common, and Hardistan, except for four minor changes. The order of varieties for the second cutting was Nebraska Common, Grimm, Meeker Baltic, Hardistan, and Ladak, except for five rather minor changes. The third cutting order was Nebraska Common, Meeker Baltic, Grimm, Hardistan, and Ladak in 7 of the 10 types of plots and 2 of these changes were based on only 0.01 ton.

An analysis of variance was used to compare the 1939 yields of varieties in each type of nursery plots with the yields of the varieties in the field plots. The F values[4] (varieties/varieties × types of plots) and the F values (varieties × types of plots/error) are given in Table 2. A high F value for the former suggests that the varieties yielded relatively the same in the type of nursery plots and field plots compared, and a high F value for the latter suggests that the varieties did not yield relatively the same in the type of nursery plots and field plots compared.

The variance analysis indicates that the yields of varieties in the field plots and in the following types of nursery plots may not be comparable: (1) Single rows 20 inches apart; (2) middle rows of three-row plots, 12 inches between rows, 20-inch alleys; (3) three rows of three-row plots, 12 inches between rows, 20-inch alleys; and (4) middle rows of five-row plots, 12 inches between rows, 20-inch alleys.

The analysis indicates that the following types of nursery plots are reliable: (1) Single rows 3 feet apart; (2) middle rows of three-row plots, 20 inches between rows, 20-inch alleys; (3) three rows of three-row plots, 20 inches between rows, 20-inch alleys; (4) three rows of five-row plots, 12 inches between rows, 20-inch alleys; and (5) five rows of five-row plots, 12 inches between rows, 20-inch alleys.

[4]SNEDECOR, GEORGE W. Calculation and Interpretation of Analysis of Variance and Covarance. Aimes, Iowa: Collegiate Press, Inc. 1934.

TABLE 2.—*The F values (varieties/varieties × types of plots) and the F values (varieties × types of plots/error) for the yields of five varieties of alfalfa grown in field plots and nursery plots, 1939.*

Field plots compared with	Varieties/varieties × types of plots*	Varieties × types of plots/error†
Single rows 3 feet apart	8.26	1.93
Single rows 20 inches apart	4.22	4.32
Middle rows of 3-row plots, 20 inches between rows, 20-inch alleys	21.66	0.44
Three rows of 3-row plots, 20 inches between rows, 20-inch alleys	28.10	0.64
Middle rows of 3-row plots, 12 inches between rows, 20-inch alleys	5.62	3.38
Three rows of 3-row plots, 12 inches between rows, 20-inch alleys	4.85	4.53
Middle rows of 5-row plots, 12 inches between rows, 20-inch alleys	3.28	1.49
Three middle rows of 5-row plots, 12 inches between rows, 20-inch alleys	24.04	0.46
Five rows of 5-row plots, 12 inches between rows, 20-inch alleys	12.41	1.29

*D.F., 4 and 4: F for 5% point = 6.39; F for 1% point = 15.98.
†D.F., 4 for varieties × types of plots and 24 for error: F for 5% point = 2.78; for 1% point = 4.22.

NUMBER OF REPLICATIONS NECESSARY TO MAKE 5% OF THE MEAN EQUAL 2 S.E.diff.

Table 3 has been prepared to show the number of replications necessary to make the value 2 times the standard error of a difference, equal to 5% of the general mean of the experiment. The formula used for computation was $\sqrt{n} = \frac{\sqrt{2}\ 2\ \text{S.E.}}{5}$, in which the denominator represents 5% of the mean; S.E., the standard error of a single determination in per cent of the mean; and n, the number of replications.

TABLE 3.—*The theoretical number of replications for field plots and nine types of nursery plots necessary to make 5% of the mean equal 2 S.E. diff., 1939.*

Type of plot	Standard error of a single determination in per cent of the mean	Number of replications
1/20 acre field plots	4.38	6.2
Single rows 3 feet apart	2.87	2.6
Single rows 20 inches apart	6.61	14.0
3-row Plots, 20 Inches Between Rows, 20-inch Alleys		
Middle rows	4.59	6.7
Three rows	2.64	2.2
3-row Plots, 12 Inches Between Rows, 20-inch Alleys		
Middle rows	3.98	5.1
Three rows	3.99	5.1
5-row Plots, 12 Inches Between Rows, 20-inch Alleys		
Middle rows	7.27	16.9
Three rows	4.91	7.7
Five rows	3.81	4.6

The types of nursery plots which seemed to require fewer or about the same number of replications as the field plots were as follows:

Single rows:
1. Three feet apart

Three-row plots, 20 inches between rows, 20-inch alleys:
2. Middle rows
3. Three rows

Three-row plots, 12 inches between rows, 20-inch alleys:
4. Middle rows
5. Three rows

Five-row plots, 12 inches between rows, 20-inch alleys:
6. Three middle rows
7. Five rows

The middle rows of the five-row plots and the single rows 20 inches apart seemed decidedly inferior to the other types of plots.

SUMMARY AND CONCLUSIONS

Five varieties of alfalfa, Meeker Baltic, Nebraska Common, Grimm, Ladak, and Hardistan, were seeded in the spring of 1938 at 10 pounds per acre in 1/20 acre field plots and in nursery plots 18 feet long. The center 16 feet of the nursery rows were harvested for yield. The types of nursery plots studied were as follows: Single rows 3 feet apart and 20 inches apart; three-row plots with rows 20 inches apart and 20-inch alleys, using the middle row and all three rows; three-row plots with rows 12 inches apart and 20-inch alleys, using the middle row and all three rows; and five-row plots with rows 12 inches apart and 20-inch alleys, using the middle row, three rows, and all five rows.

All varieties were replicated five times in Latin Square designs. The yields were calculated in tons of oven-dry hay per acre. The nursery rows were harvested once in 1938 and all plots were cut three times in 1939.

For the one cutting in 1938, the yields in tons per acre of the five varieties in the nine types of nursery plots, ranked in order from high to low, were as follows: Ladak, 1.79; Meeker Baltic, 1.60; Grimm, 1.45; Nebraska Common, 1.34; and Hardistan, 1.31. In seven of the nine types of nursery plots the ranking was the same. In the other two cases, Hardistan exceeded Nebraska Common by 0.01 ton when all the rows in the three-row plots, 12 inches between rows, were combined and by 0.05 ton in the middle row of the five-row plots.

The yields of the five varieties in tons per acre in the season of 1939 in order from high to low yields for the nine types of nursery plots and field plots were as follows: Meeker Baltic, 6.07; Nebraska Common, 5.82; Grimm, 5.77; Ladak, 5.41; and Hardistan, 5.24. This order was changed in three cases as follows: (1) The middle row of the five-row plots was changed to Grimm, 6.19; Meeker Baltic, 6.07; Nebraska Common, 5.60; Hardistan, 5.60; and Ladak, 5.54. (2) Ladak and Hardistan exchanged positions 4 and 5 in the single 20-inch rows.

(3) Nebraska Common and Grimm exchanged positions 2 and 3 in the middle row of the three-row, 20-inch plots.

An analysis of variance showed that the five varieties yielded relatively the same in the field plots and in the following types of nursery plots: Single-row plots 3 feet apart; three-row plots, 20 inches between rows, 20-inch alleys, using the middle row and all three rows; and five-row plots, 12 inches between rows, 20-inch alleys, using three rows and all five rows.

Any one of the following types of nursery plots is suggested for precise testing under irrigation: Single-row plots 3 feet apart; three-row plots, 20 inches between rows, 20-inch alleys; and five-row plots, 12 inches between rows, 20-inch alleys. These types of plots require no more replications than the field plots. It is suggested that the entire plot be harvested for yield since border effect and inter-plot competition did not noticeably affect the comparability of yields between these nursery plots and the field plots.

BREEDING FOR RESISTANCE TO CROWN RUST, STEM RUST, SMUT, AND DESIRABLE AGRONOMIC CHARACTERS IN CROSSES BETWEEN BOND, *AVENA BYZANTINA*, AND CULTIVATED VARIETIES OF *AVENA SATIVA*[1]

H. K. HAYES[2]

THE introduction in 1929 of Bond from Australia and Victoria from South America, as described by Stanton and Murphy,[3] was a direct result of a search by plant explorers throughout the world for oats highly resistant to crown rust, *Puccinia coronata*. Stanton and others[4] have described selections from crosses of Victoria with Richland that appear desirable agronomically and that are resistant to stem rust, crown rust, and the smuts.

The present paper summarizes results obtained in Minnesota from crosses of Bond with cultivated varieties of *Avena sativa*. Particular attention is given to the performance of Bond crosses in advanced generations, in individually spaced plots, and in rod-row trials, in relation to important agronomic characters.

MATERIAL AND METHODS

Cooperative studies of crown rust resistance made at Minnesota indicated that Bond had a much higher degree of resistance than Victoria and, as the early reports showed that Bond was more desirable in agronomic characters than Victoria, Bond has been used extensively in the Minnesota breeding program.

Bond resulted from a cross of *Avena sterilis* with Golden Rain and belongs to the cultivated species, *Avena byzantina*, characterized by the separation of the lower floret from the axis of the spikelet by abscission with a well-defined basal cavity on the lower grain, floret disjunction by basifracture, and conspicuous bristles on the base of the lower floret. Important differential characters of Bond and Anthony, one of the varieties crossed with Bond, are given in Table 1.

Bond was crossed also with Iogold, an early-maturing variety bred at Ames, Iowa, that has been grown extensively in southern Minnesota, Rainbow, a selection from Green Russian made in North Dakota, and two selections known as Double Crosses A and B, selected from (White Russian × Minota) × Black Mesdag. The two double cross selections have the Black Mesdag type of resistance to smut and the White Russian type of resistance to physiologic races 1, 2, and 5 of stem rust, while Iogold and Rainbow are resistant to races 1, 2, 3, 5, and 7 of stem rust. All *sativa* varieties used in crosses with Bond were susceptible to crown rust, although Rainbow has moderate resistance in some seasons. With the ex-

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1860 of the Journal Series, Minnesota Agricultural Experiment Station. Presented at the meeting of the Society held in Chicago, Ill., December 5, 1940. Prepared with the assistance of Works Project Administration Official Project No. 665-71-3-388 (3). Received for publication December 2, 1940.

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[3]STANTON, T. R., and MURPHY, H. C. Oat varieties highly resistant to crown rust and their probable agronomic value. Jour. Amer. Soc. Agron., 25:674–683. 1933.

[4]STANTON, T. R., MURPHY, H. C., COFFMAN, F. A., and HUMPHREY, H. B. Development of oats resistant to smuts and rusts. Phytopath., 24:165–167. 1934.

TABLE 1.—*Differential characters of Bond and Anthony.*

Bond	Anthony
*Early maturity	*Mid-season
*High weight per bu.	Fair bushel weight
Byzantina characters	*Sativa characters
*Lodging resistance	Fair lodging resistance
Stem rust susceptibility	*Resistance to stem rust
*Resistance to	Susceptibility to
Crown rust	Crown rust
Smuts	Smuts
*Good yielding ability	*Good yielding ability

*Desirable characters.

ception of Double Crosses A and B, the *sativa* varieties used as parents were susceptible to the collection of smut used in producing a smut epidemic.

From data collected in rod-row trials at University Farm and Waseca, 1935 to 1937, Bond proved more resistant to lodging than the sativa varieties used as parents. It gave excellent comparative yields in seasons when drought was serious.

The characters that differentiate the two species, *Avena byzantina* and *A. sativa*, are illustrated by comparing spikelets (Fig. 1) of Anthony and Bond, respectively. Studies of inheritance of differential characters in the Bond crosses have been reported by Hayes, Moore, and Stakman[5] and are briefly summarized in Table 2.

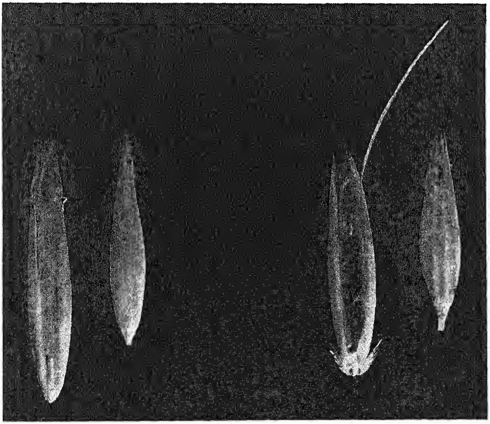

FIG. 1.—Characteristic spikes of Anthony (left) and Bond (right).

[5]HAYES, H. K., MOORE, M. B., and STAKMAN, E. C. Studies of inheritance in crosses between Bond, *Avena byzantina* and varieties of *A. sativa*. Minn. Agr. Exp. Sta. Tech. Bul. 137. 1939.

TABLE 2.—*Summary of inheritance of differential characters.*

Differential characters	Breeding behavior
Sativa vs. *Byzantina:*	
1. Spikelet disarticulation	F_1 sativa type; F_2 3S:1B
2. Floret disjunction	F_1 byzantina type; F_2, 1 factor pair in Bond × Double Crosses A and B; 2 factor pairs, at least, in other Bond crosses
3. Basal hairs, many long hairs vs. short, few or none	F_1 short, few or none: F_2, 3 short, few or none: 1 long, many
Genetic linkages:	
Character pairs 1, 2, and 3	1 and 2 C.O. value 25.7 2 and 3 C.O. value 24.0 1 and 3 C.O. value 2.7
Disease reaction:	Segregation:
1. Stem rust Resistance vs. susceptibility	F_1 resistant; F_2 3R:1S
2. Crown rust Resistance vs. susceptibility	F_1 intermediate or resistant; F_2 9R:7S
3. Smuts Resistance vs. susceptibility	Resistance dominant; 1 major factor pair in crosses of Bond with susceptible varieties; 3 factor pairs in Bond × Double Crosses A and B

From the summary it will be noted that the characters differentiating *byzantina* and *sativa* varieties are linked in inheritance. As the *byzantina* type of base appeared to be correlated with shattering of the seed, *sativa* characters were selected during the segregating generations and only a very small percentage of lines with *byzantina* characters were saved. Resistance for all three diseases was used as the main criterion of selection followed by selection for plumpness of seed and desirable agronomic characters.

Inheritance of reaction to crown rust was studied both in the seedling stages in the greenhouse and under field conditions, no attempt being made to account for minor variations in reaction. The results were explained by two complementary factors carried by Bond which in the heterozygous condition gave somewhat lower resistance than when homozygous. Torrie[6] explained crown rust reaction in a cross of Bond with Iowa No. 444 by a factor for resistance carried by Bond and an inhibitor carried by the *sativa* parent that partly inhibited the expression of the factor for resistance.

After selection for resistance, selection for plants with desirable agronomic characters was made in lines that showed resistance to all three diseases. The selection was continued in plant rows, with rows 1 foot apart and plants spaced 3 inches in the row, until the lines appeared homozygous. They were then bulked and tested in rod-row trials.

Stooling ability was studied in the F_5 to F_7 generations, both in plant rows and in replicated rod rows, and data on weight per bushel, yield, lodging, and other characters were taken in the rod-row trials. As there were wide differences in weight of grain between Bond, *sativa* varieties, and in the hybrids a correction

[6]TORRIE, JAMES H. Correlated inheritance in oats of reaction to smuts, crown rust, stem rust, and other characters. Jour. Agr. Res., 59:783–804. 1940.

was made in rate of planting in rod-row trials so that nearly the same number of seeds were sown per rod row for all strains in the trials.

It is recognized that some crosses are more desirable than others due to differences in combining ability, although there is less definite available evidence of combining ability of particular parent varieties in the small grains than for crosses between inbred lines of corn. Several sativa varieties were used as parents in the Bond crosses and the hybrids were compared with their parents and with other *sativa* varieties.

EXPERIMENTAL RESULTS

STOOLING[7]

Data for stooling in individually spaced plants were taken in 1938 and 1939 to determine whether Bond and the Bond crosses were greatly different than the *sativa* varieties. The results are given in the form of frequency distributions in Tables 3 and 4. Each entry in the table represents the mean for a 50-plant plot. Several plots distributed through the nursery were grown of each of the parents in 1938, but only a single plot for each of the hybrid lines in 1938 and for all lines in 1939.

TABLE 3.—*Means for stooling in plant rows; parents and F_5 or F_6 Bond crosses, 1938.*

	Class means for stooling			
	5.5	6.5	7.5	8.5
Parents:				
Bond	9	11		
Anthony	5			
Iogold	1	3	1	
Rainbow	2		1	
Double Cross A	5	1		
Double Cross B	1			
Bond crosses:				
Bond × Anthony	8	25	8	
Bond × Iogold	4	22	15	2
Bond × Rainbow	3	8	5	3
Bond × Double Cross A	19	12	10	2
Bond × Double Cross B	2	7	3	
Total crosses	36	74	41	7

In 1938, for example, 20 plots of Bond were distributed throughout the nursery, 9 of these falling in the class mean for 5.5 and 11 in the class mean for 6.5. The average number of stools per plant for the Bond was 6.0, for the *sativa* varieties 5.9, and for the Bond crosses 6.6.

In 1939, the mean stooling for the single-plant row of Bond fell in class 9, the average mean for all *sativa* varieties was 11, and the average of the 156 Bond crosses the same as the *sativa* varieties. There was a significant positive correlation between stooling of 154 Bond

[7]Acknowledgment is made to C. C. Tsu for his aid in studies of stooling. (See Tsu, C. C. Relation between stooling and yield in rod row trials of Bond crosses. Presented to the Faculty of the Graduate School, University of Minnesota. M.S. Thesis, December 1939.)

TABLE 4.—*Means for stooling plant rows; parents and F_6 or F_7 Bond crosses, 1939.*

	Class means for stooling				
	7	9	11	13	15
Parents					
Bond		1			
Anthony		1			
Iogold			1		
Rainbow				1	
Double Cross A			1		
Double Cross B			1		
Bond crosses					
Bond × Anthony		8	23	9	1
Bond × Iogold		6	28	8	
Bond × Rainbow		2	11	5	
Bond × Double Cross A	2	16	17	7	1
Bond × Double Cross B		2	5	5	
Total crosses	2	34	84	34	2

crosses in 1938 and 1939 of +0.30 which exceeded the 1% point as given by Snedecor's table of r.

In the rod-row trials (Table 5), the seedling count was taken for a 3-foot length of row after emergence, the number of panicles counted for the same row at maturity, and the stooling computed. There were two replications both at Waseca and University Farm, the lattice design for plot arrangement being used. Significant variability in stooling occurred at both Waseca and University Farm, but there was little relation between the two trials when only the Bond crosses were used in the comparisons, the r value being only +0.14. There was little or no relation between stooling in rod rows and in individual spaced plants. Each entry in Table 5 represents an average of four determinations, two at Waseca and two at University Farm.

TABLE 5.—*Stooling in rod-row trials at University Farm and Waseca, 1939.*

	Class means for stooling						
	0.9	1.2	1.5	1.8	2.1	2.4	2.7
Parents*		A	I	R	B		
Bond × Anthony		1	3	9	16	9	3
Bond × Rainbow			1	6	5	2	4
Bond × Iogold		1	4	15	21	1	1
Bond × Double Cross A			1	5	14	15	8
Bond × Double Cross B				1	3	7	1
Sativa varieties	1	2	5	4	1		

*A = Anthony; B = Bond; I = Iogold; and R = Rainbow.

The mean for stooling of the *sativa* parental varieties, Anthony, Iogold, and Rainbow, was 1.5; of Bond, 2.1; of 157 Bond crosses, 2.1; and of 13 *sativa* varieties included in the trials, 1.5. These results in-

dicate clearly that the Bond crosses were superior in stooling ability, on the average, to *sativa* varieties of oats considered to be adapted to Minnesota.

YIELD COMPARISONS

A frequency table for yield in bushels per acre in the rod-row trials in 1939 is given in Table 6, with two determinations at Waseca and at University Farm. The yields at University Farm were very good, but at Waseca they were less satisfactory.

TABLE 6.—*Average yield University Farm and Waseca, 1939.*

	Yield classes, bu.							
	33	40	47	54	61	68	75	82
Parents*			A	I, B			R	
Bond × Anthony		1	7	14	16	2	1	
Bond × Rainbow			5	7	5		1	
Bond × Iogold	4	2	14	10	11	2		
Bond × Double Cross A		2	7	13	15	6		
Bond × Double Cross B			3	4	1	3		1
Sativa varieties		1	7	2	2	1		

*A = Anthony; B = Bond; I = Iogold.

The *sativa* varieties gave an average yield of 58.7 bushels, Bond averaged 54 bushels, and the Bond crosses 55.1 bushels. The high average yield of Anthony, Iogold, and Rainbow, due largely to the high average yield of Rainbow of 75 bushels per acre, resulted from the fact that Rainbow, while not an outstanding yielder at University Farm, gave a much higher yield at Waseca than the average of the other varieties. Thirteen *sativa* varieties not used as parents gave an average yield of only 51.3 bushels.

Yield trials were made in 1939 in randomized blocks of approximately 25 varieties per block. Results of trials made at each of four stations, University Farm, Crookston, Morris, and Waseca, with three replications at each station, are given in Table 7 for two groups of oats.

In group I, Bond averaged 70 bushels, the *sativa* parents 75 bushels, and the Bond crosses 79.2 bushels. In group II, the parent varieties averaged 75 bushels and the Bond crosses 81.8 bushels. Class centers two classes apart give odds of approximately 19:1 that the differences in yield are significant. The crosses of Bond × Anthony were outstanding in yielding ability, while the crosses of Bond × Iogold and Bond × Double Cross A averaged lower in yielding ability.

Another series of crosses and their parents were grown at University Farm in five separate randomized block trials. The $S.E._D$ in bushels of 7.9 is an average of the five separate standard errors. The class centers for mean yields are separated by 8 bushels. The data on yields are summarized in Table 8.

The *sativa* parents gave an average yield of 75 bushels, Bond averaged 95 bushels, and the Bond crosses averaged 94.4 bushels. The results of the trials in 1940 at the central station at University Farm

and at the three branch stations indicate that many of these Bond crosses have outstanding yielding ability.

TABLE 7.—*Yield of oats in bushels per acre, average of trials at University Farm, Crookston, Morris, and Waseca, with three replications each station, 1940.*

	Class centers for yield in bushels					
	70	75	80	85	90	95
Group I						
Parents						
Gopher		1				
Double Cross A			1			
Double Cross B		1				
Rainbow	1					
Bond	1					
Bond crosses						
Bond × Rainbow	1		4		2	
Bond × Double Cross A	1	5	3	1		
Bond × Double Cross B			1	1		
	S.E.D in bu. = 4.5					
Group II						
Parents						
Iogold			1			
Anthony	1					
Gopher		1				
Bond		1				
Bond crosses						
Bond × Anthony		1	3	2	3	1
Bond × Iogold	1	3	4	2		
	S.E.D in bu. = 3.6					

TABLE 8.—*Yield of oats in bushels per acre in rod-row trials, University Farm, with three replications, 1940.*

	Class centers for yield in bushels								
	67	75	83	91	99	107	115	123	131
Parents*	A, I	2A, 2R		I, 2B	2B				
Crosses:									
Bond × Anthony	1	2	3	12	5	5	1		
Bond × Iogold		2	4	8	9	3	1		
Bond × Rainbow		1	2	9	4	2		2	1
Bond × Double Cross A	3		2	4	10	3	1		
Bond × Double Cross B		1	1	2	4	1			
Total	4	6	12	35	32	14	3	2	1
	S.E.D in bu. = 7.9								

*A = Anthony; B = Bond; I = Iogold; and R = Rainbow.

WEIGHT PER BUSHEL

One of the favorable characters of Bond is the plump kernel and high weight per bushel. During the segregating generations, selection was made for plumpness of kernel and data were taken in 1940 on weight per bushel. The results in Table 9 are an average of the trials at four stations, each mean value being the average of three replications at each of the four stations.

TABLE 9.—*Weight per bushel of parent varieties and Bond crosses, average of trials at University Farm, Crookston, Morris, and Waseca, 1940.*

	Class centers for means, lbs. per bu.								
	29	30	31	32	33	34	35	36	37
Group I									
Parents:									
Bond						1			
Double Cross A	1								
Double Cross B						1			
Rainbow			1						
Gopher					1				
Bond crosses:									
Bond × Rainbow			1			2	2	2	
Bond × Double Cross A				2	5	2	1		
Bond × Double Cross B							1		1
Group II									
Parents:									
Anthony		1							
Iogold				1					
Bond							1		
Bond crosses:									
Bond × Anthony						2	3	2	3
Bond × Iogold				1	2	1	4	1	1

5% level of significance = 1.1 lb.

The calculated 5% level of significance was 1.1 pounds and class centers were separated by 1 pound. In group I the mean weight per bushel of four *sativa* varieties was 31.8 pounds, 34 pounds for Bond, and 33.9 pounds for the Bond crosses. In group II, the *sativa* varieties averaged 31 pounds, Bond 35 pounds, and the Bond crosses 35 pounds. It is evident that selection for plumpness of grain led to the isolation of Bond crosses that were the equal of the Bond parent in average weight per bushel.

Similar results were obtained for the trials conducted only at University Farm and given in Table 10.

The means for the *sativa* parents used in the Bond crosses only give an average weight per bushel of 24.6 pounds at University Farm. The weight per bushel of Bond and of the Bond crosses was about the same, the average weight per bushel of the crosses being 33.6 pounds.

TABLE 10.—*Weight per bushel at University Farm in rod-row trials with three replications, 1940.*

	Class centers for means, lbs. per bu.							
	20	22.5	25	27.5	30	32.5	35	37.5
Parents:								
Bond						2	2	
Iogold			1	1				
Anthony	1	1	1					
Rainbow			1	1				
Bond crosses:								
Bond × Iogold					4	11	7	5
Bond × Anthony					2	8	11	8
Bond × Rainbow				1	1	7	9	3
Bond × Double Cross A		2			4	11	6	
Bond × Double Cross B		1				2	2	4
Total crosses		3		1	11	39	35	20

5% level of significance = 2.3 lbs.

DISCUSSION OF OTHER CHARACTERS

Bond was outstanding in its ability to withstand lodging and selection was practiced during the segregating generations for resistance to lodging. Of the 39 Bond crosses grown at each of the four stations, 20 were the equal of Bond in resistance to lodging. In the trials at University Farm where lodging was especially severe, 14 Bond crosses out of 109 that were tested were equal in lodging resistance to Bond. The results indicate that it is possible to select strains that are superior in ability to withstand lodging by selection from Bond crosses.

An apparently undesirable character of Bond is a decided tendency to secondary growth that was very evident in the rod-row trials where the rate of seeding was heavy. As this character was not evident in the individually spaced plants, it was impossible to select against it. Many of the hybrids showed a decided tendency to this secondary growth, although secondary growth in the hybrids was less noticeable, on the average, than in Bond. Whether the character of secondary growth will be a serious disadvantage can only be determined by studying the more desirable hybrids under conditions of normal planting with the grain drill. The red color of the grain of Bond oats is undesirable as a character in sections where white and yellow grain color is preferred. Many of the hybrids have reddish color of grain, others bred true for white or yellow grain color. Other hybrids are variable in grain color.

SUMMARY

The Bond variety of oats has been used extensively in Minnesota as a parent in crosses with *sativa* varieties. It excels in resistance to crown rust and smut, in plumpness of grain, and in ability to withstand lodging. Data presented on inheritance of characters that differentiate *sativa* and *byzantina* oats, and on reaction to crown rust,

stem rust, and the smuts, show that it is relatively easy to combine resistance to the three diseases with the desirable characters of the two parents. Many of the Bond crosses tested in replicated rod-row trials are equal or superior to Bond in weight per bushel. Some appear outstanding in yielding ability and in ability to withstand lodging here. These results indicate that the Bond variety is desirable as a parent in crosses with varieties of *Avena sativa*. If further data substantiate the results already obtained, the Bond variety may be classed as having good combining ability.

SOME OBJECTIVES IN BREEDING FOR YIELD AND OTHER AGRONOMIC CHARACTERS IN WHEAT[1]

W. W. WORZELLA[2]

IN considering the objectives in breeding for yield and other agronomic characters in wheat, one must include the objectives having immediate and practical value, as well as those involving the accumulation of basic facts or the establishment of fundamental principles. It is evident that they should reflect a sound analysis and probable solution of our present problems and demands. Obviously, the specific demands of a particular locality or territory will determine the amount of emphasis to be placed on any particular problem. However, the objectives of a fundamental nature, such as a study of the nature of various characters, their inheritance, interrelationships, and synthesis, will have general application.

Because of the varied demands for wheats and their products, the objectives cannot be static but must be ever changing. Our aim is, not only a stable wheat crop, but also one that is more uniform and superior in quality to our present wheats. We do not want varieties that produce large crops some years and failures in others, but rather those that are able to resist the rigors of hard winters, drought, delayed harvests, etc., and that produce a uniform crop. Since wheat is the raw material that goes into the production of many foods and other products, new varieties must be "built up" to meet the requirements of these specific demands. The purpose of this paper, therefore, is to discuss several pertinent objectives that should aid in the breeding of superior wheats, and to analyze them in the light of our present knowledge.

INVENTORY OF WHEATS AND THEIR CHARACTERS

The first objective of a sound breeding program must involve an inventory of all wheat varieties and their characteristics. This includes not merely a cataloging of strains and varieties, but the recording of their individual characteristics, particularly those having superior germ plasm. As more information regarding the nature, adaptation, and usefulness of these characteristics becomes available, it should be recorded. A good inventory, therefore, makes available and keeps up to date all the information regarding the raw materials. It is a compilation of facts on wheat representing a digest and summary of the work of many investigators. One must not only know his own material, but also be familiar with the work of other investigators before he can proceed intelligently and effectively in a constructive breeding program.

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ANALYSIS OF CHARACTERS

The next objective has to do with the analysis of characters or the splitting up of characters into their component parts. Much can be learned about yield, winterhardiness, drought resistance, adaptation, etc., by breaking them down into their component parts and studying each separately and in combination with each other. A knowledge of these components is necessary before one can intelligently synthesize new varieties superior in these more complex characters. At present, fortune plays a very large part in determining the possibility of obtaining desirable results. A cross is made between two varieties in the hope of getting something superior in yield, drought resistance, etc., provided one is able to recognize and accurately measure these characters. Although our present knowledge is rather fragmentary, a good start has been made in the analysis of yield, winterhardiness, and drought resistance. It seems, therefore, that a brief review of our present knowledge regarding some of these characters will not only remind us of the problems involved, but also will illustrate the usefulness and value of such an analysis.

Of the many characters present in wheat, yield, no doubt, is the most difficult to analyze. Yield may be regarded as the ultimate expression of all environmental conditions and inherent factors that have integrated throughout the life of the plant. The determination of gross yield by the rod-row or field test method is unquestionably important and necessary for the final selection of superior yielding strains. Unfortunately, its costliness, its non-analytical nature, or its inability to reveal the component parts, as well as other limitations associated in the early stages of selection, make it unsuited as the sole measure of yield. Fundamentally, the analysis of yield should comprise the identification of its component parts and a study of their nature, interrelationships, and behavior under varying environmental conditions. The plant breeder is interested primarily in the inherent factors affecting yield, since they represent the components that can be permanently modified by breeding. Of course, we can not overlook the importance of the environmental factors, since they greatly affect the physiology and morphology of the plant in a way that is directly related to yield.

Several measurable and inherent factors for yield have been determined by investigators in this country and in England. The characteristics that have been found to contribute to yield in wheat are (a) number of plants per unit area, (b) number of heads per plant or per unit area, (c) yield per head, and (d) size of head. These characteristics that have been found to be associated with yield represent only the beginning in the analysis of this character. Other factors, such as long and short season plants, tall and short varieties, wide and narrow leaves, rate of growth, sterility, intensity of chlorophyll, etc., may prove to be inherent factors affecting yield. Answers about the influence of these and other factors await solution.

Winterhardiness, a very important character, has been studied extensively. Of its components, three, namely, cold, heaving, and smothering resistance, have received most attention. Probably no single factor of winterhardiness has been studied more extensively

than cold resistance. Injury or killing due to cold or low temperatures consists in the withdrawal of water from the cells to form ice in the intercellular spaces. This process mechanically injures the tissue or the increased concentration of cell sap causes the protoplasm to precipitate. Also, certain conditions have been found to be associated with wheat plants that are hardened and more cold resistant. Hardened wheat plants are higher in sugars and amino acids, possess a greater amount of bound water or hydrophylic colloids, and have a higher osmotic pressure. Because of these associations, several chemical tests have been proposed to measure cold resistance. However, since other factors, such as wilting, degree of hardening, etc., also cause these changes, no chemical test yet devised has proved very satisfactory. The actual freezing test, conducted under artificially controlled conditions in a cold chamber, is the best method for determining cold resistance in wheat. By its extensive use much has been learned about the relative cold resistance of varieties, as well as the nature and inheritance of this component of winterhardiness. The results of experiments show that cold resistance is definitely inherited. Its mode of inheritance is governed by multiple genetic factors and it can be and has been successfully transferred and combined with other agronomic characters. Such concrete and useful knowledge regarding an important component of winterhardiness is very pleasing to the wheat breeder.

The winter injury caused by heaving of the plants due to alternate freezing and thawing has been investigated only recently. Observations, particularly in the northeastern section of this country, indicate that injury from heaving is not the same for all varieties. Studies are being made of root systems, including their tensile or breaking strength, in an effort to develop an empirical technic for isolating lines resistant to heaving damage.

Not much has been reported on the winter injury due to smothering of wheat plants under ice, water, and tightly packed snow. There is disagreement among investigators as to whether injury to the plant by smothering is due to lack of oxygen or the accumulation of toxic substances. Likewise, very little is known regarding the relationships that exists between the anatomical structure of plants and their winterhardiness. Observations have been made indicating that those varieties that have the vegetative or growing point most deeply buried show the least winter killing. Some wheats are "firm sleepers", that is, they do not respond to brief periods of favorable growing weather but remain dormant and hardened. Much more needs to be known concerning these and other factors of winterhardiness.

Drought resistance is an important character in wheat production, especially in the semi-arid regions of the world. The short harvests of 1892 and 1921 in Russia, due directly to drought conditions, were a national calamity and millions of human lives were lost through starvation. There is seldom a year in which some of our wheat-growing area is not subjected to drought in some degree. Investigators recognize two types of drought, namely, (a) soil drought, in which the soil becomes too dry to provide the plant with sufficient water to replace that lost by transpiration, and (b) atmospheric drought,

caused by hot and dry winds, resulting in the desiccation of the plants. Drought chambers have been developed recently which are used in appraising wheats for this character. It has been demonstrated that the varieties Baart, Ceres, and Milturum are resistant, while Hope and Marquis are quite susceptible to injury under dry and hot conditions. Attempts have been made recently to associate certain morphological and physiological characters with drought resistance in different varieties. Relationships have been noted between the relative drought resistance of wheats and their root systems, rate of water loss, water requirements, and the amount of bound water in the tissues. However, we need to know more about the nature of the components of drought resistance before we are able to breed specifically for this character.

Another character, descriptively referred to as "external dress", often determines the extent to which a new wheat will be grown commercially. It includes those external features that make a wheat stand out above others, that sell a variety and give one satisfaction in its development. It involves such attributes as uniformity, color, shape, and size of plants and of the grain. Also, a type of a plant that reflects vigor, sturdiness, and productivity; grains or kernels that are fairly large, true to color, and uniform in size and texture which will result in a good appearing sample. Varieties that have undesirable "external dress", either inherent or the result of mechanical mixtures, cannot be regarded as very satisfactory.

Space does not permit of an analysis of other characters, such as lodging, earliness, adaptation, shattering, etc., but this brief review of our present knowledge regarding yield, winterhardiness, drought resistance, and "external dress" illustrates the need and use of such analyses. It is only by such analyses that we can understand these complex characters and synthesize new varieties according to prescription. Probably because some of these characters seem intricate and very complex, there is a feeling among some that nothing can be done about it. The writer does not share that feeling. The results to date in the analysis of yield, winterhardiness, quality, and disease resistance furnish plenty of evidence that progress can be made.

DEVELOPMENT OF SPECIFIC TESTS

The next objective has to do with the development of specific tests for identifying and accurately measuring wheat characteristics. Before a test can be of much use it must be simple, accurate, and specific. By its use one should be able to test at least several hundred wheats each year. Also, it should appraise the merit of a strain when only a few grams of wheat or a few plants are available so that it can be used to ascertain the desired facts on segregating generations. The importance and need of specific tests already have been emphasized. It might be added that it is a relatively simple matter to make crosses in wheat and produce thousands of new genotypes. However, the difficult task is to recognize what is valuable in this large mass of material, most of which is worthless. At the Purdue Agricultural Experiment Station, specific tests are used very ex-

tensively in the wheat breeding program. For example, in appraising the character "quality" we are using the fermentation time test as a guide to gluten strength, the granulation test to determine the index of particle size, the total carotenoid pigment content for color, and the test weight for flour yield. For winterhardiness the strains are subjected to the artificial freezing test produced in a cold chamber. Pathologists subject these same strains to mosaic, leaf rust, and stem rust infections in special disease nurseries. These tests are all conducted on the segregating generations in an effort to pick out a limited number of desirable genotypes to be advanced to the rod-row plots for more complete testing. Plant breeders often remark that their plant materials increase so rapidly that it is difficult to reduce the strains to a satisfactory working number. Our experience has been to the contrary. By the use of these specific tests most of the undesirable types have been sifted out and eliminated, and only a relatively few remain to be tested in the advanced rod-row plots. Specific tests, therefore, not only are tools for greater efficiency and economy, but also furnish a sound basis for selection and help to remove the guess work in breeding.

SEARCH FOR NEW AND SUPERIOR GERM PLASM

A search for new and superior germ plasm should be regarded as a permanent objective of a sound breeding program. The fact that wheat is a self-fertilized plant, resulting in rather uniform populations of plants that are homozygous for most characters, greatly reduces the possibility of finding new genotypes. Many wheats are phenotypically alike, but quite different genotypically. Largely by the hybridization of different lines, that must be done artificially, are we able to produce new variants which result from the segregation and recombination of different genes. Selfing tends to bring about homozygosity in varieties and thus eliminate much of the variation commonly observed in populations of cross-fertilized plants. Many genes, especially those conditioning quantitative characters, have been lost or "laid aside" by much the same process as the plant breeder uses in selecting a brown chaff variety instead of one with white chaff, or *vice versa*. If we expect to make permanent changes in such characters as yield, adaptation, earliness, lodging, etc., we must locate and isolate additional genes that condition these characters, so that, in the production of a superior variety, they can be synthesized into new varieties which combine the desirable characters of the present ones.

There are several sources of germ plasm available to the wheat breeder. Many of our present varieties are merely heterogeneous populations made up of strains differing widely in their genotypic behavior. The fact that, in studies involving hybrid material, new characters are recombined, while others show transgressive inheritance, clearly indicate that our wheats are genotypically different, and possess different pairs of genetic factors for the same characters. Another source of germ plasm is the large amount of unproved foreign material that has been collected by workers of the U. S. Dept. of Agriculture. This material has been kept viable and is available. Are

we as individual wheat breeders using and taking advantage of this valuable source of germplasm? Also, our knowledge is quite inadequate in regard to the wheats of older regions. The remote localities of Asia and Africa possess endless numbers of wheats yet unknown. A thorough search for and an analysis of all cultivated and wild species and closely related genera should furnish the germ plasm needed for the synthesis of characters that make up a superior variety.

FUNDAMENTAL RESEARCH IN NATURE AND BEHAVIOR OF CHARACTERS

To breed intelligently for specific objectives we need more fundamental information regarding the nature, manner of inheritance, and inter-relationships of characters. Most breeding programs, through the use of empirical trials, have been concerned primarily with practical and immediate objectives and have given little attention to the accumulation of basic facts or to the establishment of fundamental principles. Consequently, our knowledge regarding most characters is fragmentary and fortune plays a major role in determining success. It is true that many superior varieties have been developed by the use of empirical trials; however, considerably more progress has been made with methods involving sound and basic principles.

In order to "build up" or synthesize new varieties most directly we must obtain more basic information concerning our varieties and their characteristics. We need to know more about how to analyze some of these complex characters. What constitutes a unit and how can it be isolated and measured? Research is needed in the determination of the mode of inheritance of characters. What is the true relationship that exists among the genes conditioning such characters as yield, winterhardiness, earliness, etc.? Can we develop varieties that are high yielding and at the same time early? Only recently it has been shown that cold resistance and quality are not genetically linked. If associations are found, are they genetic or of a physiological nature? What is the effect of environmental conditions on the expression and development of these characters? Many more cause and effect relations that must be determined could be cited, but these suggest the type and kind of basic information needed. Such data must be obtained, not as a by-product or something incidental to the regular breeding operations, but rather as the result of a systematic and sustained attack, studying each factor separately and in combination with others. Such studies call for experiments that have been especially designed and carried on to solve definite and specific problems. Many of these tests will have to be conducted for several years and under varied conditions before consistent and reliable data are obtained. Such data, carefully verified, represent permanent progress toward the attainment of our objectives.

SUMMARY

In this discussion an attempt has been made to examine critically a few pertinent objectives and to emphasize their importance in breeding for yield and other agronomic characters in wheat.

Obviously, much basic research is needed if we hope to solve many of the problems involved and expect to synthesize new wheats effectively and intelligently. Future demands and new developments in technic and methods, no doubt, will create new objectives and help attain some of the present ones. In the meantime, as more information is obtained and used, new varieties will be released that are superior in yield, winterhardiness, specific adaptation, and other characters.

Such improvements reflect, not the final goal in wheat breeding, but definite progress towards the attainment of desired objectives.

NOTES

RECOVERY AFTER CUTTING AND DIFFERENTIALS IN THE INJURY OF ALFALFA BY LEAFHOPPERS (*EMPOASCA FABAE*)

AN unusual differential in leafhopper injury to alfalfa occurred in a varietal trial on the University Farm at Madison, Wis., in 1940. The second growth of this alfalfa was severely injured by leafhoppers in fairly sharply defined areas, while much larger and contiguous areas under the same cutting treatment were practically free from such damage. Such differentials in leafhopper injury were not directly associated with the varieties of strains included in this trial. In this instance, the adult leafhoppers which survived the first cutting appeared to express a definite preference for egg-deposition in the alfalfa of the areas where the recovery of the second growth was more rapid and succulent due to larger supplies of subsoil moisture. The details of this observation are reported because of their possible significance in the interpretation of the causes of uncommon differentials in leafhopper injury of the second growth of alfalfa, and because of their implications in the evaluation of strains and varieties of alfalfa for such qualities as resistance to or escape from such insect injury.

Thirteen varieties and strains of alfalfa were sown on a 3-acre area in triplicated and randomized plats (11 × 60 feet) on July 21, 1938. The alfalfa was cut twice annually in 1939 and 1940 at deferred stages of growth and in the latter year the first cutting was taken on June 26. As a rule, the removal of the first crop of alfalfa in southern Wisconsin during the last week of June eliminates serious leafhopper injury in the second growth since egg deposition will have approached completion in the first growth and the spent adults will have died. Moreover, the vitality of the eggs and of the wingless nymphs which may have hatched from them is destroyed in the drying of the hay of the first crop. By deferring the first cutting, the principal source of infestation of the second growth is eliminated, a situation much in contrast to cutting the first crop about two weeks earlier, which permits a large number of surviving adults to complete egg deposition in the young second growth.

As has been true in certain years, cool weather in the late spring of 1940 resulted in the continuance of egg deposition for a longer period in early summer than normally prevails. Many unspent adults laid eggs in the young second growth of the varieties and strains of alfalfa which were recovering after cutting on June 26, and marked areal differentials in the injuries by nymphs occurred in July and August.

The 3-acre varietal trial was located along the lower end of a fairly steep slope with the exception of a contiguous area of about ¼ acre that was low and flat. In years past heavy rains had cut three more or less parallel but widely spaced ravines up and down the slope and in each ravine a narrow gully occurred in 1938 about 40 days after the alfalfa was sown. These gullies were kept filled and packed with green and dry hay at intervals during 1939 and 1940 to prevent further erosion. This treatment retarded the surface run-off water from

higher elevations and added much to the reserves of surface and sub-soil moisture in the ravines. From the standpoint of moisture accumulations, the ravines had much of the topographical advantages which prevailed with the low flat area.

Reserves of sub-soil moisture were very low in the trial area during the spring and early summer of 1940. This was due to the high water requirements of alfalfa and to dry weather, especially during the latter half of 1939. The deficit in the precipitation for the first six months of 1939 was 3.31 inches, or 21.4% of the normal of 15.39 inches, and for the last six months the deficit was 8.33 inches, or 50.0% of the normal of 16.65 inches. The growth of alfalfa in the first half of 1940 was dependent largely on current rainfall which totalled 13.1 inches, or 15% below normal. Although 3.4 inches of rainfall occurred on June 22 and 23, 1940, all of the alfalfa was relatively slow in recovery after cutting on June 26 except on the low area and in the three ravines, and in those plots on the higher ground where very non-hardy varieties had been thinned to a few scattered plants by winter-killing in 1938–39. While the alfalfa on such areas made the most rapid recovery, it became very yellow and stunted in late July and in August, showing clear-cut evidence of severe leafhopper injury. The slower growing alfalfa of the plots with good stands on the higher and drier areas remained green and practically free of leaf-hopper injury. The gradations between the injured and uninjured alfalfa were abrupt, occurring in most cases for a distance of less than 3 feet.

That these marked areal differences in leafhopper injury were due to corresponding differences in the populations of nymphs was made evident at frequent intervals in late July when, with the mere brush of the hand in the areas of yellowed alfalfa, very large numbers of young wingless nymphs were collected, while only one or two per hand sweep were obtained in the green alfalfa of the higher areas nearby.

The actual differences in populations were ascertained on August 7 by sweeps with 4 × 4 inch cardboards mounted on sticks. One face of the cardboard was covered with glue which not only collected but held the wingless nymphs as well as the relatively few winged adults so that they could be counted.

The mean of the leafhopper counts (one count per sweep with at least six sweeps taken on each area) in the alfalfa of the low area and of the three ravines on August 7 was 40.7, while the mean of the counts on comparable areas of higher elevation was only 2.8. It appeared that egg deposition was concentrated in the alfalfa which recovered more rapidly and which was more succulent as a result of greater supplies of subsoil moisture. If the egg depositions had been at random and not preferential or selective, then it is to be assumed that the eggs in the less succulent and slower growing alfalfa failed to hatch or the nymphs were not capable of surviving. This seems unlikely since it is known that eggs laid in relatively mature alfalfa hatch rapidly and produce virile nymphs. Whatever may have been the case, it is very clear that there was no expression of preference or selectivity which could be attributed directly to qualities inherent

in any of the 13 varieties or strains of alfalfa used in this trial. They consisted of such very non-hardy strains of common as the South African, Argentinean, and Chilean which were severely thinned by winterkilling during the first winter (1938–39); regional strains of American Common from Oklahoma and Utah in which less serious winter losses prevailed; regional strains of South Dakota and Kansas origin which had fairly good survival; and the very hardy variegated varieties Grimm and Cossack and two imported strains from France and Transylvania, all of which had excellent survival. Losses were minor during the second winter, even with the less hardy types. Since only a very thin stand remained after the first winter in the plats of the African, Argentinean, and Chilean commons, their recovery after cutting on June 26, 1940, was more rapid and succulent as a result of greater reserves of subsoil moisture. On the basis of symptoms, the scattered plants in such plats on the higher areas were injured as severely as those of the thick stands of much hardier varieties in the ravines and on the low area. However, with such wide differences in the density of the alfalfa it was very difficult to make leafhopper counts in the plats with thin stands which would be comparable with the counts in the plats with good stands. Attempts to do this were abandoned, although it was determined that the individual plants of the plats with very thin stands were heavily infested with leafhopper nymphs.

Had the plats of this trial not been triplicated and randomized, the contrasts in leafhopper injury might have been attributed to inherent differences in the varieties and strains instead of differences based on the behavior of the insect in egg-deposition and the responses of the second growth to environmental variables in subsoil moisture. Unfortunately, Ladak alfalfa was not included in this series of plats. Had it been, some information on the relation of its inherent slow recovery after the first cutting to subsequent leafhopper injury, might have been obtained. This remains to be determined along with the many other problems of leafhopper injury which may be associated with selectivity in egg deposition.

Additional counts made on August 15, 20, 23, and 30, 1940, revealed the usual late-summer decline in leafhopper populations in alfalfa fields of southern Wisconsin. The means of the leafhopper counts in the alfalfa of the three ravines and of the low area were 17.2, 15.0, 12.3, and 0.9, respectively, for the above dates as compared with 1.5, 1.4, 1.5, and 0.9, respectively, for areas of higher elevation nearby.—L. F. GRABER, *University of Wisconsin, Madison, Wis.*

NEW TECHNIC DEVELOPED IN MEASURING THE DIAMETER OF THE COTTON FIBER[1]

IN a recent paper,[1] the writer discussed the measurement of the diameter of cotton fibers. During the past two years the methods formerly used here have been modified in an effort to make the work less tedious and the measurements more accurate. Mercerized mature

[1]MOORE, JERRY H. Measuring the diameter of the cotton fiber. Jour. Amer. Soc. Agron., 30:604–609. 1938.

fibers are now stained in Congo red before drying and the diameters are measured directly by using a celluloid metric rule.

The mature fibers are mercerized and washed as indicated in the paper, referred to, but are then stained for 12 hours or longer in a 0.5% aqueous solution of Congo red. After washing in three or more changes of water, the dyed fibers are partially dried on paper towels, and drying is completed at room temperature. The fibers are stained red and are more easily seen and measured with the micro-projector than when unstained. Glass vials, 45 mm by 15 mm, are very useful in the mercerizing, staining, and washing of the fibers, especially where the investigator is dealing with many samples.

The stained and air-dried fibers are mounted in mineral oil on a glass slide, but instead of marking with a pencil the fiber diameters on a sheet of white paper and then measuring them, the operator measures the diameters, projected on a sheet of white paper, directly to the nearest 0.5 mm by the use of a celluloid rule graduated in millimeters. Each diameter is entered on a recording sheet. The direct measurement with the rule eliminates much of the fatigue and improves the accuracy of the measurements.

The diameters of many thousands of fibers are being measured in the cotton fiber laboratory at the North Carolina Experiment Station without the excessive fatigue which accompanies many measurements made under the microscope.—JERRY H. MOORE, *Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C.*

BOOK REVIEW

THE BIOCHEMISTRY OF SYMBIOTIC NITROGEN FIXATION

By Perry W. Wilson. Madison, Wis.; University of Wisconsin Press. XIV + 302 pages, illus. 1940. $3.50.

THIS monograph is published as a sequel to "The Root Nodule Bacteria and Leguminous Plants" of E. B. Fred, I. L. Baldwin, and Elizabeth McCoy, published in 1932. It is considerably more technical, although a shorter book than the earlier publication.

The author begins with two introductory paragraphs on the nitrogen economy of man and nature and leguminous plants in agricultural history. Following this the biochemistry of the organisms under discussion is taken up in detail. Considerable attention is given to the question as to whether vitamins or other growth accessory factors are necessary in the metabolism of these organisma; also to the interactions between bacteria and their hosts; while the mechanism of nitrogen fixation by bacteria is quite fully discussed. The last-mentioned subject is really the primary point taken up by the author and one chapter is given over to a discussion of the various chemical theories that have been proposed to explain the process.

The book ends with a chapter on practical applications of legume bacteria, with suggestions as to how recent developments may indicate new fields of application. (H. J. C.)

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SUMMER MEETING OF CORN BELT SECTION

THE summer field meeting of the Corn Belt Section of the Society will be held at the Purdue University Agricultural Experiment Station, Lafayette, Indiana, June 19 to 21, inclusive.

SUMMER MEETING OF NORTHEASTERN SECTION

THE summer meeting of the Northeastern Section of the American Society of Agronomy will be held at the University of New Hampshire, Durham, N. H., June 25, 26, and 27. An invitation is extended to Canadian agronomists to attend and participate in membership in this Section of the Society.

For further information about this meeting, write to Ralph W. Donaldson, Secretary-Treasurer, Northeastern Section, American Society of Agronomy, Massachusetts State College, Amherst, Mass.

NEWS ITEMS

DOCTOR A. L. FROLICK, Associate Professor of Agronomy, University of Nebraska, died on January 27 at Fort Leavenworth, Kansas. Doctor Frolick had been on leave of absence from the University of Nebraska since October 1, when he was called to active duty as a major of infantry in the United States Army.

"IF THEY COULD SPEAK", a 56-page booklet containing 95 four-color illustrations of plant food deficiency diseases in field plants, is just off the press. The color plates were made from kodachrome transparencies and the range of subjects includes boron, calcium, copper, iron, magnesium, manganese, nitrogen, potash, and zinc deficiencies in alfalfa, apples, beets, blueberries, cabbage, carrots, cauliflower, celery, citrus, corn, cotton, cucumber, dogwood, grapes, endive, romaine lettuce, milkweed, oats, peanuts, peaches, peppers, potatoes, raspberries, roses, rutabagas, snap beans, soybeans, squash, sweet potatoes, swiss chard, tobacco, tomatoes, velvet beans, and wheat. Each plate is accompanied by a descriptive identification. Those desiring copies of this booklet may obtain them by writing to Chilean Nitrate Educational Bureau, Inc., 120 Broadway, New York, N. Y.

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RESULTS OF A 5-YEAR FACTORIAL EXPERIMENT WITH POTATO FERTILIZERS[1]

G. V. C. HOUGHLAND AND W. O. STRONG[2]

POTATO growers on the Eastern Shore of Virginia from time to time have had to deal with certain soil and fertilizer problems, which although not peculiar to this section, have been intensified by local growing conditions. Among these is the problem regarding the use of inorganic and organic sources of nitrogen in the fertilizer, the related problem dealing with fertilizer reaction, and more recently the problem concerning water-soluble or insoluble sources of magnesium to be used in the fertilizer.

It is recognized that these problems are not necessarily encountered on all potato fields, nor is it usual to find all of them represented on one field, although this occasionally happens. The simultaneous occurrence of all three problems might be explained by the relationship that can be expected to exist between source of nitrogen, fertilizer reaction, and source of magnesium in fertilizers used on certain types of fields for a period of years. The results of certain investigations may be cited to illustrate this point. In a comparison of different nitrogen sources on the Eastern Shore of Maryland (3),[3] the senior author found that a 70:30 inorganic-organic nitrogen ratio in a 6–6–5 potato fertilizer produced better yields over a 4-year period than mixtures with one-half the nitrogen from nitrate of soda and the remainder from sulfate of ammonia. In this comparison it is important to note that in addition to the difference in nitrogen source the former mixture was also 20 % less acid-forming than the latter.

In Alabama (6), the use of highly acid-forming sources of nitrogen in cotton fertilizers over a period of 6 years resulted in a marked increase in soil acidity. Corresponding amounts of nitrogen from organic sources had little effect on the soil reaction, indicating the relationship existing between source of nitrogen and fertilizer reaction.

From studies conducted at the Tennessee Experiment Station, MacIntire and Shaw (4) state that, "Dolomitic limestone and high calcic rocks have equal value for general rotations." The two materials can be comparable in their neutralizing power. Kieserite, or mag-

[1]A cooperative project between the Virginia Truck Experiment Station, Norfolk, Va., and the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication September 23, 1940.

[2]Associate Soil Technologist, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Superintendent, Eastern Shore Experimental Farm, Virginia Truck Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 199.

nesium sulfate, on the other hand, apart from being soluble, is a neutral salt lacking entirely the property of correcting acidity possessed by dolomitic limestone. Because of these facts, Carolus (1) recommends the use of dolomitic limestone on potato soils below pH 5.0 and soluble magnesium (magnesium sulfate) where the soil reaction is already too high to risk the occurrence of scab through the use of limestone. Therefore, the relationship between soluble and insoluble sources of magnesium is not alone one of solubility but also of fertilizer reaction. Although these problems, their relationships, and occurrence are not regarded as widespread in scope, at least for the present, nevertheless they are considered of increasing importance particularly to most potato growers in the Eastern Shore section of Virginia and throughout the Coastal Plain region.

A study of the three problems, nitrogen source, magnesium source, and fertilizer reaction, was undertaken at Onley, Virginia, in 1935. The field chosen for the location of the experiment was carefully selected on the basis of tests indicating low organic matter supply, high soil acidity, and low magnesium content, which placed it in a group of fields likely to respond to the treatments under consideration.

PLAN OF EXPERIMENT

It was decided that the factors under study in the present experiment could be expected to have not only individual effects, but also inter-related effects, which

TABLE 1.—*Formulation of 6–6–5 fertilizer mixtures.*

Treatment No.	Inorganic—organic nitrogen ratio	Source of magnesium	Reaction*
1	80:20	MgO from kieserite (soluble) equivalent to treatment 4	⅓ neutralized with $CaCO_3$
2	80:20	MgO from dolomitic limestone (insoluble) to neutral reaction	Neutral with dolomitic limestone
3	80:20	MgO from kieserite (soluble) equivalent to treatment 2	Neutral with $CaCO_3$
4	80:20	Dolomitic limestone (insoluble) to ⅓ neutral reaction	⅓ neutralized with dolomitic limestone
5	60:40	MgO from kieserite (soluble) equivalent to treatment 8	⅓ neutralized with $CaCO_3$
6	60:40	MgO from dolomitic limestone (insoluble) to neutral reaction	Neutral with dolomitic limestone
7	60:40	MgO from kieserite (soluble) equivalent to treatment 6	Neutral with $CaCO_3$
8	60:40	Dolomitic limestone (insoluble) to ⅓ neutral reaction	⅓ neutralized with dolomitic limestone

*Reaction refers to the acid-forming or non acid-forming properties of the fertilizer when applied to the soil, as determined by the method of Pierre (Ind. & Eng. Chem., Anal. Ed., 5:229–234. 1933.)

made it imperative that all factors be represented in the same experiment. The factorial design is ideally suited for such an investigation.

Since three main factors are stipulated, namely, nitrogen source, magnesium source, and fertilizer reaction, it was found convenient and considered adequate to use a $2 \times 2 \times 2$ factorial design consisting of eight treatments with six replications. The 6-6-5 fertilizer mixtures were formulated as shown in Table 1.

In compounding the fertilizer mixtures, the plan given below was followed as regards nitrogen sources:

Inorganic—organic nitrogen ratio	Units of nitrogen derived from				Acidity equivalent in lbs. $CaCO_3$
	$(NH_4)_2SO_4$	$NaNO_3$	Fish scrap	Tankage	
80:20.........	3.6	1.2	0.6	0.6	362
60:40.........	2.7	0.9	1.2	1.2	296

The ratio of ammonia nitrogen to nitrate nitrogen was the same in each mixture. The phosphoric acid was supplied as superphosphate and the potash as muriate. The mixtures were all applied at the rate of 2,000 pounds per acre.

Previous experience at Onley, Virginia, with randomized-block field arrangements had established the particular advantages of this design when machinery was used for planting and harvesting; therefore a design of this type was selected. It was necessary, however, to use multiple-row plots in order to study the cumulative effects of applying the same treatment to a plot year after year. Accordingly, four-row plots were used with six replications laid out in randomized-block design in two sections of 24 plots each, the original random arrangement remaining each succeeding year. The rows in the sections were 110 feet long spaced 30 inches with hills approximately 15 inches apart.

CONDUCT OF THE EXPERIMENT

Certified Irish Cobbler seed potatoes were planted, using an assisted-feed potato planter that placed the fertilizer in bands on each side of the seed piece at or slightly below seed level. It was necessary to calibrate the planter for each fertilizer mixture. This was accomplished by first determining the wheel turns along a measured row while the machine was in operation. Use of this number of turns of the wheel was made later to secure delivery of the proper amount of fertilizer through adjustment of the hopper opening while the machine was jacked up. In this way comparatively accurate fertilizer delivery was obtained in the field.

The two center rows of each plot were harvested and passed over a mechanical grader with 1 ⅞ inch openings in the belt. Yield records were made on the weights of primes and seconds, these grades being based on size only.

YIELDS OBTAINED

In Table 2 the average yields of primes from the eight treatments are listed for each year. The yields were unusually low in 1936 on account of dry weather, consequently that year it was considered advisable to harvest the entire plots of four rows each. The yields throughout the 5-year period are also considered low for this section; however, it should be remembered that the field selected for the

experiment was not representative of the section as a whole but rather represented a type of field considered suitable for the experimental work.

TABLE 2.—*Average yields in bushels per acre of potatoes with two sources of nitrogen, two sources of magnesium, and two fertilizer reactions.*

Treatment No.	Fertilizer composition*			Yields in bu. per acre				
	Inorganic—organic ratio	Reaction	Mg supply	1935	1936 †	1937	1938	1939
1	80:20	⅓ neutralized	Kieserite	151	57	132	146	109
2	80:20	Neutral	Dolomitic limestone	150	61	134	141	110
3	80:20	Neutral	Kieserite	165	66	146	143	112
4	80:20	⅓ neutralized	Dolomitic limestone	152	60	111	146	107
5	60:40	⅓ neutralized	Kieserite	142	59	127	157	117
6	60:40	Neutral	Dolomitic limestone	146	61	146	140	127
7	60:40	Neutral	Kieserite	152	64	155	155	125
8	60:40	⅓ neutralized	Dolomitic limestone	155	56	151	161	124

*6–6–5 fertilizer applied at the rate of 2,000 lbs. per acre each year.
†All four rows of plots harvested instead of the two middle rows.

ANALYSIS OF RESULTS

Table 3 gives yearly analyses of the experiment and presents an opportunity afforded only through this type of design and analysis for a critical review of the behavior of main effects and interactions of the treatments throughout the 5-year period.

It will be noted first that the variance contributed by blocks was fairly uniform during 4 of the 5 years with an exception in 1937 when there was a decided increase. In general, however, if block variance is accepted as a measure of soil variation, there was no indication of wide differences in this respect.

Treatment response also showed considerable uniformity from year to year, except for the marked increase in 1937. When this result was obtained it was thought at first that the continued application of the different treatments had begun to take effect and it was believed that this would result in a widening of the differences in yields from the various treatments as the experiment progressed. The results in 1938 and 1939, however, did not prove this point, although the mean squares for treatments in each of these years was larger than in 1935 or 1936, and in 1939 exceeded the 5% point. The marked increase in treatment response in 1937 as compared with the other years illustrates how easily fallacious conclusions may be drawn from experimental results of short duration, especially when the treatments are

TABLE 3.—*Analysis of factorial experiment with potatoes, pounds per plot.*

	Degrees of freedom	Mean squares				
		1935	1936	1937	1938	1939
Total	47	—	—	—	—	—
Blocks	5	995.92	942.78	1296.86	725.04	803.58
Treatments:	7	159.47	160.27	715.94†	222.86	224.25*
N source	1	225.33	10.08	1258.70†	634.38	1302.08†
Mg source	1	15.19	105.02	143.52	64.17	3.00
Reaction	1	93.52	760.02*	1518.75†	399.63	143.52
Interactions:						
First order:						
N×Mg	1	188.02	21.33	1015.68†	35.88	88.02
N×reaction	1	54.19	0.09	73.51	103.54	3.00
Mg×reaction	1	533.33	105.02	249.34*	194.21	24.08
Second order:						
N×Mg×reaction	1	6.75	120.33	752.08†	128.38	6.02
Error	35	208.76	123.60	56.51	255.75	89.78
General average, bu. per acre	—	151.5	60.4	137.6	148.6	116.6
Standard error, %	—	5.1	4.95	2.9	5.8	3.5

*Z exceeds 5% point.
†Z exceeds 1% point.

likely to be influenced by unpredictable seasonal effects as in the present case.

When the mean squares for error are compared from year to year a considerable amount of variation will be found. These differences also appear in a similar comparison of the standard errors, but it will be observed that none of the standard errors is excessively high, especially in the light of previous experience with similar fertilizer experiments.

A question may be raised concerning the cause of the differences in error mean squares. It should be remembered that this item in the analysis, although listed as error, really represents all the unaccounted-for variation that occurs between plots within the blocks. Although only the total of this variability can be estimated, yet from experience and personal observation some of the contributing sources can be enumerated. In the present experiment some of these sources were differences in vigor of seed caused by cutting habits of seed cutters; differences in the care taken by pickers in harvesting, especially when the potatoes were plowed out according to local custom; differences in occurrence of diseases, such as Rhizoctonia; and finally, slight differences in subsoil which were found to exist within block areas. All these causes, and perhaps others not mentioned, unquestionably had a varied influence on the mean squares for error from year to year.

The treatment mean squares were broken down into the various contributing components designated as main effects, first order interactions, and second order interactions, a procedure peculiar to this type of experimental analysis. Considering first the main effects, it

will be seen that in 2 years out of 5, nitrogen source contributed sufficient variance to gain significance, and it will be noted that in 1938 the variance contributed was much greater than the other two main effects under study, although significance was not attained. Magnesium source, on the other hand, was not significant any year, and every year it contributed the least of the main effects toward treatment variance. Fertilizer reaction, like nitrogen source, was significant 2 years of the 5.

The analysis, of course, is not complete until the interactions of the main effects have been given consideration. The interactions of nitrogen source with magnesium source and magnesium source with fertilizer reaction, attained significance only in 1937. The second order interaction involving all three factors, although usually negligible, also showed significance in 1937. This may be taken to indicate that all three factors were not entirely without influence in the production of the highest yields for that season.

The results in Table 2 may be further analyzed by grouping the data in several ways in order to make comparisons of the average yields per acre obtained from different treatment combinations. Table 4 shows the results of such groupings listed as "Main Effects" and "Secondary Effects" for the 5-year averages and for the year 1937. The results for 1937 are given separately to enable economic consideration of the treatment differences during a year when response from "treatments" was highly significant.

The results of the comparisons of average yields made under "Main Effects" (Table 4) show that the yield from the 40% organic nitrogen mixtures was 14 bushels higher than that from the 20% mixtures in 1937. Over the 5-year period, the higher organic nitrogen mixture also showed an average increase amounting to 6 bushels. These increases are statistically significant as judged from the requirements at the 5% level for 1937 and for the 5-year period, respectively. It may be stated that in the 5-year analysis, treatment variance exceeded the 1% level of significance.

A number of relationships may be considered in discussing the results under "Secondary Effects" in Table 4, but perhaps the most important of these may be summed up as follows: Comparisons of kieserite and dolomitic limestone without considering the source of nitrogen (section A of Table 4) show that kieserite was more effective in neutral and less effective in one-third neutral fertilizers. Considering next the relationship of magnesium source to nitrogen source (section B of Table 4), it appears that in general where dolomitic limestone was used throughout, the 40% organic nitrogen mixtures outyielded the 20% mixtures. This difference in favor of the 40% mixture was significant for 1937 and also for the 5-year average. When kieserite was used there was very little difference between the two levels of organic nitrogen.

When the data are considered from the standpoint of the two organic nitrogen levels it will be seen that 20% mixtures containing kieserite produced significant increases over those containing dolomitic limestone. However, the 40% organic nitrogen mixtures containing kieserite produced lower yields than the corresponding mix-

tures with dolomitic limestone. Summarizing this table, it appears that 20% organic nitrogen yielded best with kieserite, whereas 40% organic nitrogen produced better yields with dolomitic limestone. This differential response was significant in 1937 as shown by the values for N×Mg interaction in Table 3.

Consideration of fertilizer reaction in relation to source of nitrogen, disregarding source of magnesium, is possible from section C of Table 4. Mixtures that were completely neutralized showed increased yields when 20% organic nitrogen was increased to 40%. This in-

TABLE 4.—*Factorial fertilizer experiment with potatoes, Onley, Va., comparisons, of average yields in bushels per acre.*

Main Effects (Significance Requirement at 5% level=4.0 bu., 1935–39; 5.7 bu. 1937)

	Differences in bu.	
	1935–39	1937
40% organic nitrogen minus 20% organic nitrogen	6†	14.0*†
Kieserite minus dolomitic limestone	2	4.2
Neutralized minus ⅓ neutralized	4†	14.7*†

Secondary Effects (Significance Requirement at 5% level=5.7 bu., 1935–39; 8.1 bu., 1937).

(A) Source of magnesium and fertilizer reaction

Source of Mg	Fertilizer reaction				Differences, bu.	
	Neutral		⅓ neutral			
	1935–39, bu.	1937, bu.	1935–39, bu.	1937, bu.	1935–39	1937
Kieserite	128	150	120	130	8†	20*†
Dolomitic limestone	122	140	122	131	0	9*†
Differences	6†	10†	−2	−1	—	—

(B) Source of magnesium and source of nitrogen

Source of Mg	Source of nitrogen				Differences, bu.	
	40% organic		20% organic			
	1935–39, bu.	1937, bu.	1935–39, bu.	1937, bu.	1935–39	1937
Kieserite	125	141	123	139	2	2
Dolomitic limestone	127	149	117	123	10†	26*†
Differences	−2	−8**	6†	16*†	—	—

*Economic gain.
**Economic gus.
†Statistically significant.

TABLE 4.—(*Concluded.*)

(C) Fertilizer reaction and source of nitrogen

Fertilizer reaction	Source of nitrogen				Differences, bu.	
	40% organic		20% organic			
	1935–39, bu.	1937, bu.	1935–39, bu.	1937, bu.	1935–39	1937
Neutral............	127	150	123	140	4	10†
⅓ neutral..........	125	139	117	121	8†	18*†
Differences.........	2	11*†	6†	19*†	—	—

*Economic gain.
**Economic loss.
†Statistically significant.

crease was significant in 1937. However, mixtures that were only one-third neutralized produced larger increases with 40% organic nitrogen. Examining the data from the standpoint of nitrogen source, it will be seen that 20% organic nitrogen mixtures produced significant increases in yield when completely neutralized, as shown in 1937 and from the averages for the 5 years. These results tend to bear out the contention that the reaction of fertilizer warrants greater consideration now than formerly because of the decrease in the use of organic sources of nitrogen, these having been largely replaced by highly acid-forming nitrogen materials which require neutralization for the maintenance of maximum yields.

A question may be raised concerning the differences in cost of the fertilizers and the relationship increased cost may bear to the increase in yield. It is considered that economic significance (5) is established when the yield difference between two treatments exceeds the statistical requirement for significance plus the difference in cost of the two treatments expressed in bushels of potatoes at current price. The assumption is made that the effects of the treatments are measurable principally on the particular crop harvested.

In 1937, the cost of the 40% organic nitrogen mixtures averaged approximately $3.00 more per ton than the 20% mixtures, which in terms of potatoes at 50 cents per bushel gives a requirement of 6 bushels for cost equalization. The requirement for statistical significance in 1937 at the 5% level was 5.7 bushels for comparison of main effects, making a total of 11.7 bushels required for economic significance between these two fertilizers. There was an average difference of 14 bushels in favor of the 40% organic nitrogen fertilizer (Table 4) in 1937, indicating that under the conditions of the experiment this mixture was profitable that year.

Similar estimations of cost for the neutral as compared with the one-third neutral fertilizers gave a requirement for economic significance of 6.7 bushels. The average increase obtained through complete neutralization was 14.7 bushels in 1937. The use of kieserite in 1937, however, gave an increase of only 4.2 bushels which is less than

the 5.7 bushels required for statistical significance and therefore was neither statistically nor economically significant. However, the effects of the dolomitic limestone and of the kieserite are undoubtedly continued to some extent for more than one season.

The differences shown under "Secondary Effects" in Table 4 have been tested for economic significance as previously described by using the appropriate cost differentials combined with the requirement of 8.1 bushels for statistical significance. From the comparisons kieserite as used in this experiment in mixtures neutralized with calcium limestone produced an average increase of 10 bushels over similar mixtures containing dolomitic limestone; this increase, however, was statistically, but not economically, significant. Similarly, in neutralized mixtures, the use of 40% organic nitrogen produced an average increase of 10 bushels over 20% which was also statistically but not economically, significant when the cost of the treatment was considered. In all, nine treatment comparisons were economically significant and these are indicated in Table 4. In one case there was an economic loss, when kieserite was used with 40% organic nitrogen.

EFFECT OF FERTILIZERS ON SOIL REACTION

Ever since the introduction of neutral fertilizers in potato production, considerable interest and speculation has arisen regarding the question of the desirable degree of neutralization and the possible effect of complete neutralization on the occurrence of potato scab. The present experiment affords a means of throwing some light on these questions because half of the mixtures were completely neutralized and half were one-third neutralized with pulverized limestone.

Fig. 1 shows the initial reaction (pH) of the 48 plots as determined in 1935 at the start of the experiment. Thereafter, 24 plots received one-third neutralized and the remaining 24 completely neutralized fertilizers each year for the 5-year period. The present reaction of each

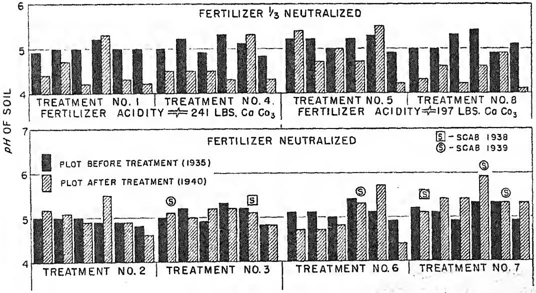

FIG. 1.—Soil reaction as affected by continued use of 6–6–5 fertilizer of differing equivalent acidity.

plot was determined in March, 1940, and these results are also represented in the diagram.

Where the one-third neutralized fertilizers were used there is strong evidence that the soil reaction was reduced from an average of approximately pH 5.0 to about pH 4.5. There were some exceptions to this trend, but these comprised only a small minority of the plots tested.

Where the completely neutralized fertilizers were used continuously since 1935, there was little change indicated from the average soil reaction of about pH 5.0.

Scab occurred on two of the neutral fertilizer plots in 1938 and on five plots in 1939, as indicated in Fig. 1. No scab occurred on the plots continuously treated with similar fertilizer which was only one-third neutralized. These results suggest that the occurrence of scab was favored by the larger amounts of limestone applied in the neutral fertilizer, thus accounting for the appearance of scab at soil reactions usually regarded as unfavorable to the growth of the scab organism. The occurrence of scab, of course, depends also on the distribution as well as the activity of the scab organism. However, randomization and replication of the treatments with respect to fertilizer reaction, as provided in the present experimental design, should equalize the probability of scab occurrence for all plot treatments.

DISCUSSION

The use of a factorial design in the present experiment unquestionably has made possible an efficient use of the experimental facilities available, as well as an extremely important examination of main effects and interactions, which can be done simultaneously only in such a design. The advantages of the factorial design in these and other respects have been fully discussed by Fisher (2), Yates (7), and others.

In planning the present experiment it was necessary to omit an entirely acid-forming fertilizer treatment, since one of the requirements for properly combining the results to compare the two sources of magnesium made it necessary to provide a fertilizer acid in reaction but containing insoluble magnesium. To fulfill this condition dolomitic limestone ordinarily would be added to the mixture, thus reducing the acidity. A compromise was effected by using fertilizers completely neutralized and one-third neutralized. The exclusion of a highly acid-forming fertilizer may account for the failure of magnesium-deficiency symptoms to develop in the field. However, when the experiment was planned in 1935, excessive and prolonged acidity of the soil was generally accepted as a probable cause of magnesium deficiency, so the experiment was planned rather from a preventive viewpoint than to provide proof of the cause. Nevertheless, some information was obtained regarding the trend of soil pH after the continued use of fertilizers differing in equivalent acidity.

SUMMARY

1. Field tests with potatoes were made in factorial design with eight 6–6–5 fertilizer mixtures made up to give comparisons between

80:20 and 60:40 ratios of inorganic to organic sources of nitrogen, between a soluble and an insoluble source of magnesium, and between completely neutralized and one-third neutralized fertilizers. There were six replications of each treatment.

2. The main effects of the fertilizer treatments show that the 60:40 inorganic-organic nitrogen ratio gave higher average yields than the 80:20 ratio. The completely neutralized fertilizer produced a higher average yield than a similar mixture only one-third neutralized. There was little difference in yields produced from soluble and insoluble sources of magnesium for the 5-year period.

3. The secondary effects indicate that complete neutralization of the fertilizer was more effective when soluble magnesium was supplied; but when the mixture was only one-third neutralized, there was little choice between soluble and insoluble magnesium sources.

4. The fertilizers with 80:20 inorganic to organic nitrogen ratios produced better yields with soluble magnesium, whereas the fertilizers with 60:40 ratios produced higher yields with magnesium from insoluble source.

5. With mixtures having an 80:20 ratio of inorganic to organic nitrogen, complete neutralization was more effective than was the case with the 60:40 ratios.

6. Main effects and interactions for 1937 were tested from an economic as well as a statistical viewpoint. It was found that kieserite, as used in this experiment, with additions of calcium limestone to neutralize the fertilizer, produced increases over dolomitic limestone which were statistically, but not economically, significant. This was also the case in neutral mixtures when 40% organic nitrogen was compared with 20%. Nine of the treatment comparisons were found to show economic gains, but an economic loss was indicated when kieserite rather than dolomitic limestone was used with 40% organic nitrogen.

7. The continued use of neutral fertilizer over a period of 5 years showed no definite tendency to increase the pH of the soil above the initial reaction of about pH 5.0. The use of fertilizer only one-third neutralized, however, showed a decided tendency to lower the pH of the soil from the initial reaction of about pH 5.0 to approximately pH 4.5.

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RELATION BETWEEN YIELDING ABILITY AND HOMOZYGOSIS IN BARLEY CROSSES[1]

F. R. IMMER[2]

THE relation between yielding ability and homozygosis in selfed lines of naturally cross-pollinated crops, particularly corn, is well known. The reduction in yield is greatest during the early generations of inbreeding and becomes progressively less as inbreeding is continued. The rapidity and extent of the reduction in yield varies with the genetic nature of the original open-pollinated varieties or F_1 crosses and with the individual inbred lines.

The present study gives information on the amount of heterosis[3] in F_1 crosses between varieties of barley and the reduction in yield during successive generations of natural selfing in the same crosses.

MATERIALS AND METHODS

Six varieties of barley were used to make six crosses as follows:

Parent varieties	Crosses
Wisconsin No. 38	Wisconsin No. 38×Chevron
Velvet	Wisconsin No. 38×C.I. 2492
Chevron	Wisconsin No. 38×Olli
C.I. 2492	Wisconsin No. 38×Minsturdi
Olli	Velvet×Chevron
Minsturdi	Velvet. ×C.I. 2492

All of these six crosses combine certain desirable character combinations and can be expected to be of value in a breeding program.

In 1938 a yield test of the parent varieties and F_1 crosses was conducted in randomized blocks with each variety or F_1 cross grown in single-row plots, of 11 plants each, spaced 5 inches apart in the row, except for the F_1 crosses of Wisconsin No. 38×Chevron, Wisconsin No. 38×Minsturdi, and Velvet×Chevron, in which two-row plots were used. Six replications were used. Two plants of the variety Lion were grown at the end of each row and removed before harvest in order to control differential growth adjacent to the alleys. The yields of the parent varieties and three of the crosses were based on a possible total of 66 plants each. In the other three crosses mentioned a possible total of 132 plants of each cross were grown. The percentage stand obtained in this test was good, an average of 10.2 plants per row being obtained at harvest from 11 seeds planted.

Replicated yield trials were made in 1939 of the parent varieties and F_2 and F_3 generations of the same crosses. The seed of F_1 and F_2 plants was bulked and used for planting the F_2 and F_3, repsectively. This test was made in five randomized blocks of single rod-row plots planted at the standard rate of seeding. In

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[3]In this paper heterosis is considered as an increase over the average of the parents for the characters under study.

1940 a yield test of the parent varieties, F_2, F_3, and F_4 crosses was made in five randomized blocks of three-row plots planted at the standard rate and only the central row harvested for yield. Bulk seed from the plots of the previous generation was used.

EXPERIMENTAL RESULTS

The number of heads per plant, seeds per head, weight per seed (in grams), and yield per plant (in grams) were determined for each plant of the parent varieties and F_1 crosses grown in 1938. The means per plant were calculated for each row and then for the mean of the six replications. The data were analyzed on the single row basis. In Table 1 is presented the means of the characters mentioned above.

The standard errors of the difference between the means of the parent varieties and F_1 crosses, given below each character in Table 1, are on the basis of a single row per plot. The crosses Wisconsin No. 38×Chevron, Velvet×Chevron, and Wisconsin No. 38×Olli were grown in two row plots. Examination of the data showed that the variance between plots of these three crosses was not significantly different from the variance between paired rows. The standard error of the mean for these three crosses would be given by dividing the standard deviation by $\sqrt{12}$ instead of $\sqrt{6}$ as would be necessary for the other crosses and the parents. The standard errors of the difference in Table 1 are on the basis of six plots of single rows and may be used as a minimum error for all comparisons.

In number of heads per plant all F_1 crosses exceeded the mean of the two parents. In one cross only, that of Velvet×Chevron, did the F_1 reach the parent with the higher number of heads per plant. As an average of all F_1 crosses the number of heads per plant exceeded the low parent by three-fourths of the difference between the low and high parents.

All F_1 crosses exceeded the mean of the parents in number of seeds per head. Four of the six crosses exceeded the higher parent. In the two crosses involving C.I. 2492, the F_1 approached the higher parent more closely than the lower but did not reach it.

The results from the comparison of the F_1 with the parents for weight per seed were more variable. In three crosses the F_1 exceeded both parents, in one cross the F_1 had lower seed weight than either parent and in two crosses the F_1 was essentially the same as the average of the parents.

The yields of the F_1 plants exceeded the yields of the higher yielding parent in four crosses but significantly so in only one, that of Wisconsin No. 38 Minsturdi. In the two crosses involving C.I. 2492, the F_1 exceeded the average of the parents numerically, but did not reach the higher parent. The virtual absence of heterosis for yield in the cross of Wisconsin No. 38×C.I. 2492 was due to the relatively small amount of heterosis for number of heads per plant and seeds per heads and the fact that in weight per seed the F_1 approached the smaller seeded parent. The great increase of the F_1 of Wisconsin No. 38×Minsturdi was attributable to the extreme heterosis for number of seeds per head and weight per seed.

TABLE 1.—*Mean number of heads per plant, seeds per head, weight per seed, and yield per plant of parent varieties and F_1 crosses in 1938.*

Cross	Parent varieties ♀	Parent varieties ♂	Parent varieties Av.	F_1	Difference between F_1 and average of parents
Number of Heads per Plant					
Wis. No. 38×Chevon	7.4	9.8	8.6	9.2	+0.6
Wis. No. 38×Minsturdi	7.4	12.2	9.8	10.4	+0.6
Velvet×Chevron	8.1	9.8	9.0	9.9	+0.9
Wis. No. 38×Olli	7.4	5.1	6.2	7.0	+0.8
Wis. No. 38×C.I. 2492	7.4	5.6	6.5	6.8	+0.3
Velvet×C.I. 2492	8.1	5.6	6.8	7.5	+0.7
Av. S. E. difference = .49	—	—	7.82	8.47	+0.65
Number of Seeds per Head					
Wis. No. 38×Chevron	45.5	46.4	46.0	49.7	+3.7
Wis. No. 38×Minsturdi	45.5	31.8	38.6	47.0	+8.4
Velvet×Chevron	45.1	46.4	45.8	50.5	+4.7
Wis. No. 38×Olli	45.5	44.5	45.0	50.5	+5.5
Wis. No. 38×C.I. 2492	45.5	31.2	38.4	40.5	+2.2
Velvet×C.I. 2492	45.1	31.2	38.2	41.9	+3.7
Av. S.E. difference = 1.80	—	—	42.00	46.68	+4.68
Weight per Seed in Grams					
Wis. No. 38×Chevron	0.0237	0.0223	0.0230	0.0248	+0.0018
Wis. No. 38×Minsturdi	0.0237	0.0249	0.0243	0.0288	+0.0045
Velvet×Chevron	0.0206	0.0223	0.0214	0.0214	0.0000
Wis. No. 38×Olli	0.0237	0.0216	0.0226	0.0244	+0.0018
Wis. No. 38×C.I. 2492	0.0237	0.0222	0.0230	0.0219	−0.0011
Velvet×C.I. 2492	0.0206	0.0222	0.0214	0.0212	−0.0002
Av. S.E. difference = .00082	—	—	0.0226	0.0237	+0.0011
Yield per Plant in Grams					
Wis. No. 38×Chevron	8.20	10.23	9.22	11.42	+2.20
Wis. No. 38×Minsturdi	8.20	9.75	8.98	14.13	+5.15
Velvet×Chevron	7.53	10.23	8.88	10.75	+1.87
Wis. No. 38×Olli	8.20	5.02	6.61	8.78	+2.17
Wis. No. 38×C.I. 2492	8.20	3.92	6.06	6.12	+0.06
Velvet×C.I. 2492	7.53	3.92	5.72	6.70	+0.98
Av. S.E. difference = .843	—	—	7.58	9.65	+2.07

It is of some interest to note that the three higher yielding F_1 crosses came from parents whose average yields exceeded considerably the yields of the parents in the other three crosses.

As an average of all crosses the F_1 exceeded the average of the parents by 8.3% in number of heads per plant, 11.1% in number of seeds per head, 4.9% in weight per seed, and 27.3% in yield per plant. The yield per plant is obtained by multiplying number of heads per

plant × number of seeds per head × weight per seed. The yield per plant is, therefore, completely specified by the three components measured. Consequently, the average heterosis for yield per plant of all crosses must be greater than any one of the three components into which it was here separated since the F_1 exceeded the average of the parents for each of the components. Multiplying together the three components, $1.083 \times 1.111 \times 104.9 = 126.2\%$. This differs slightly from the 127.3% obtained directly from the average of the single plot yields since the latter was calculated from the mean product of the components for the individual plants and the former from the product of the component means.

In Table 2 are given the yields in bushels per acre of the parent varieties and crosses grown in 1938–1940. The yields per plant of the parents and F_1 crosses given in Table 1 are here converted to bushels per acre for direct comparison. The 1939 and 1940 results are based on five replicated rod-row plots of parent varieties and crosses. The 1938 results were based on six replicated space-planted plots with 11 plants per row.

The standard errors given for each year are for comparison among the separate parent varieties and crosses. To compare a given cross with the average of both parents, the standard error of the difference given would need to be multiplied by $\sqrt{3/4}$.

In 1939 all crosses in F_2 yielded more than the average of the parent and five of them significantly so. Five of the six crosses in F_3 exceeded the average of the parents in 1939, but only one was significantly higher in yield. In 1940 all crosses in F_2 and F_3 and five of the six in F_4 yielded more than the average of the two parents. Five of the crosses in F_2 and three in F_3 significantly exceeded the average yield of the parents.

The average increase of the F_1 crosses over the mean of the two parents was 27%. In 1939 the average increase of the F_2 crosses over the parental averages was 34% and dropped to 9% for the F_3 compared with the parents. In 1940 the average increases of the F_2, F_3, and F_4 over the average of the parents was 19%, 14%, and 5%, respectively. A definite and progressive reduction in yield took place in the crosses as selfing led to a progressive increase in homozygosity.

The mean yields of the parents, F_2, and F_3 for both 1939 and 1940 were calculated and are given in Table 3.

As an average of the two years the mean of the six crosses in F_2 and F_3 exceeded the average of the parents by 24% and 13%, respectively. This is a reduction of 11% as homozygosity increased from 50% to 75%. This would suggest that as the percentage of homozygosity approaches 100 the average yield of the bulk progenies of the crosses would approach, approximately, the mean yield of the parents. The percentage increase of the F_4 crosses over the average of the parents would, from these data, be expected to be $13 - {}^{11}/_{2}$ or $7\frac{1}{2}\%$. The percentage obtained in 1940 was 5%. The difference is well within the limits of experimental error. The expected reduction in yield with successive generations of inbreeding would depend on the nature of the interaction of factors for yield and on natural selection during the inbreeding process.

TABLE 2.—*Mean yields in bushels per acre of parent varieties and crosses grown in 1938–1940.*

Cross	Yield in bushels per acre			
	Parent varieties			F_1
	♀	♂	Av.	
1938 Results				
Wis. No. 38×Chevron	39.4	49.1	44.2	54.8
Wis. No. 38×Minsturdi	39.4	46.8	43.1	67.8
Velvet×Chevron	36.2	49.1	42.6	51.6
Wis. No. 38×Olli	39.4	24.1	31.8	42.2
Wis. No. 38×C.I. 2492	39.4	18.8	29.1	29.4
Velvet×C.I. 2492	36.2	18.8	27.5	32.2
Av.	—	—	36.4	46.3
S.E. difference = 5.73 bu.				

1939 Results

Cross	Parent varieties			F_2	F_3
	♀	♂	Av.		
Wis. No. 38×Chevron	39.3	33.7	36.5	43.1	32.0
Wis. No. 38×Minsturdi	39.3	19.1	29.2	46.8	39.0
Velvet×Chevron	40.0	33.7	36.8	50.0	37.0
Wis. No. 38×Olli	39.3	40.2	39.8	46.0	44.4
Wis. No. 38×C.I. 2492	39.3	15.9	27.6	40.8	31.4
Velvet×C.I. 2492	40.0	15.9	28.0	38.8	32.3
Av.	—	—	33.0	44.2	36.0
S.E. difference = 4.88 bu.					

1940 Results

Cross	Parent varieties			F_2	F_3	F_4
	♀	♂	Av.			
Wis. No. 38×Chevron	78.7	52.4	65.6	67.2	73.6	72.0
Wis. No. 38×Minsturdi	78.7	49.6	64.2	69.3	66.6	50.1
Velvet×Chevron	62.7	52.4	57.6	80.5	73.2	66.4
Wis. No. 38×Olli	78.7	61.5	70.1	81.0	71.2	70.5
Wis. No. 38×C.I. 2492	78.7	31.9	55.3	65.8	66.6	59.8
Velvet×C.I. 2492	62.7	31.9	47.3	64.9	61.2	59.5
Av.	—	—	60.0	71.4	68.7	63.0
S.E. difference = 5.80 bu.						

The two crosses involving C.I. 2492 produced the lowest yields in F_1, F_2, and F_3 and were exceeded only by one other cross in F_4 and then not significantly so. It is apparent that these two crosses possessed a smaller proportion of high-yielding genotypes in the segregating generations and this was predictable from the F_1. The crosses

of Wisconsin No. 38 × Olli and Velvet × Chevron produced the highest yields in F_2 and F_3 as an average of two years and were among the highest in F_4, being exceeded in F_4 by Wisconsin No. 38 × Chevron alone but not significantly so. These two crosses were intermediate in yield in F_1.

TABLE 3.—*Mean yield in bushels per acre of parent varieties and crosses for an average of 1930–40.*

Cross	Yield in bushels per acre		
	Av. of parents	F_2	F_3
Wis. No. 38×Chevron	51.0	55.2	52.8
Wis. No. 38×Minsturdi	46.7	58.0	52.8
Velvet×Chevron	47.2	65.2	55.1
Wis. No. 38×Olli	55.0	63.5	57.8
Wis. No. 38×C.I. 2492	41.4	53.3	49.0
Velvet×C.I. 2492	37.6	51.8	46.8

It is to be expected in some years that the agreement between F_1 and F_2 or F_3 will be reduced through the interaction of crosses × type of test. In F_1 the seed supply is small and space-planted rows must be used. In F_2 or F_3 the seed supply should be adequate for replicated tests in drilled rows. A very apparent interaction was evident when comparisons were made between the data obtained from space-planted plots in 1938 and drilled plots in 1939 and 1940. Minsturdi was exceeded in yield in space-planted rows by only one variety and then by only 2.3 bushels per acre. In drilled rows Minsturdi ranked fifth in yield among the six varieties in both years. The cross of Wisconsin No. 38 × Minsturdi was outstanding in yield in space-planted rows in 1938 but did not perform in the same manner in F_2 or F_3 in drilled rows.

In 1940 a special test was made of the yields of the six parent varieties in drilled rows with approximately 600 seeds per row and in space-planted rows with the seeds spaced 5 inches apart. Five replications were used, the experimental design being one of "split plots." The average yield of all varieties was 45.0 bushels per acre in drilled rows and 47.9 bushels per acre in space-planted rows. Tillering was unusually great. The mean squares for varieties (over both types of of tests), varieties × type of test, and error were 1,040, 285, and 67, respectively. The value of F for comparing interaction with error mean square (for $N_1 = 5$ and $N_2 = 40$ degrees of freedom) exceeded the 1% level of significance.

From these data it may be suggested that when several crosses are available the average yield of the crosses may be determined in replicated yield trials in the early segregating generations. The use of the F_1 generation as a means of determining the average yields in later generations would appear to be limited seriously. The small amount of seed available for tests in F_1 would compel space planting. It was evident in this study that the yield performance in space-planted rows may differ greatly from performance of the same varieties or crosses in drilled rows.

It would appear that yield trials of bulk crosses in F_2 or F_3 properly replicated and conducted in several places in the region in which the crop is to be grown and preferably for several seasons would provide a method for determining the average yield performance of the different crosses. Only the high-yielding crosses would be saved. These, presumably, have the highest proportion of high yielding genotypes and would be continued in the breeding program. Such a method of testing the relative ultimate value of several crosses would be most valuable when the bulk method of breeding is to be used during the early segregating generations. Single plant selections in later generations would isolate true-breeding, high-yielding strains.

SUMMARY

The extent of heterosis for number of heads per plant, seeds per head, weight per seed, and yield per plant was determined in six crosses between varieties of barley. The yield in relation to the parent varieties was determined in replicated yield trials of the same crosses in F_2, F_3, and F_4. The yield of the parent varieties was compared also with the average yield of the F_2, F_3, and F_4 generations for each of the six crosses.

As an average of all crosses the F_1 exceeded the average of the parents by 8.3% in number of heads per plant, 11.1% in number of seeds per head, 4.9% in weight per seed, and 27.3% in yield per plant.

The average yield of six crosses in F_2 and F_3 in replicated trials, as an average of two years, exceeded the average of the parents by 24% and 13%, respectively. In F_4 the average increase in a single year test was 5% over the average of the parents.

It is suggested that the average yield performance of different crosses may be determined by means of replicated yield trials in the F_2 or F_3 generations. Such yield trials may be used for discarding certain crosses since the proportion of high-yielding genotypes in the low-yielding crosses will be less than in crosses with a higher average yield.

THE SEGREGATION OF GENES AFFECTING YIELD PREPOTENCY, LODGING, AND DISEASE RESISTANCE IN F_3 AND F_4 LINES OF CORN[1]

G F. SPRAGUE AND A. A. BRYAN[2]

THE development of hybrid corn is one of the very striking illustrations of the contributions of research to practical agriculture. In Iowa in 1932, for example, approximately 4,000 acres were planted to hybrid corn, while in 1939 the hybrid corn acreage was approximately 7,500,000 acres. This is nearly a 2,000 fold increase during a seven-year period. In addition to the increased acreage grown, there has been, also, a considerable improvement in the hybrids offered for sale during this period.

In the final analysis the value of hybrid corn to the farmer is based on the inbred lines available for use. The development of methods which will make for a more efficient production or evaluation of new inbred lines will eventually be of benefit to the hybrid corn industry and the farmer who uses hybrid seed.

In 1935, Jenkins (1)[3] presented data indicating that inbred lines exhibited their hybrid combining potentialities very early in the inbreeding process and that the combining ability was not materially affected by selection in later generations. This somewhat unexpected finding was explained, "on the basis that yield was controlled by a large number of dominant genes, many of which have approximately equal effects. Esssentially equal numbers of dominant alleles will be preserved by chance through the successive generations of selfing even though accompanied by segregation for particular dominant alleles."

More recently, additional data have been presented by Jenkins (2) dealing with segregation of genes affecting yield of grain. A yield test was conducted comparing the top cross performance of 16 siblings among each of seven S_1 plants of the variety Krug. On the basis of the variation among sibling plants within lines, theoretical mean square values were calculated for successive generations of selfing. These values indicated that, theoretically, it would be possible to detect segregation for yield factors in the S_7 generation. Practical considerations, however, indicated the importance of testing lines for yield prepotency earlier in the course of inbreeding.

The investigations reported here were undertaken to furnish additional evidence on the segregation of genes for yield prepotency, lodging and disease resistance in the F_3 and F_4 generations of inbreeding.

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[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, cooperating with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Journal paper J-792 of the Iowa Agricultural Experiment Station. Project 411. Received for publication December 4, 1940.

[2]Agronomist and former Agronomist, respectively, Division of Cereal Crops and Diseases, collaborators, Agronomy Section, Farm Crops Sub-section, Iowa Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited," p. 214.

MATERIALS AND METHODS

The material chosen for study originated from self pollination of the single cross L 317 × B1 345. Seventy-three F_3 lines were produced from unselected F plants and top crossed by the open-pollinated variety Krug. Yield trials of this top-crossed material were conducted in 1934 and 1935. Yields in 1934 were erratic due to drought. The 1935 yield data are presented graphically in Fig. 1.

The top-cross yields of the 73 F_3 lines ranged from 61 to 79 bushels per acre. One of the inbred parents, L 317, produced a top-cross yield of 71 bushels, the other inbred parent, B1 345, and the variety Krug yielded approximately 65 bushels each. The percentage of erect plants ranged from 54 to 70 and the percentage of damaged kernels from 7.6 to 34.0.

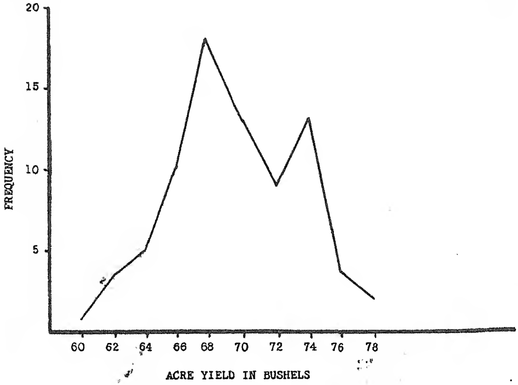

FIG. 1.—Frequency distribution of the acre yields of 73 F_3 lines top-crossed by Krug. (1935 data.)

On the basis of these tests, 12 F_3 lines were chosen among which were represented all possible combinations of high, medium, and low yielding ability, high and low resistance to lodging, and high and low resistance to disease. Each of these lines was then selfed an additional generation, five F_4 ears being selected to represent each F_3 family. These 60 lines and the parental inbreds were top crossed with Iowa synthetic 8037, a multiple cross involving 16 inbred lines. Thirty plants of each line were grown in the top-crossing field and the seed produced was bulked. The data presented were obtained from the yield comparisons of the top-crossed material in 1938 and 1939. The experimental design used in both years was an 8×8 triple lattice with six replications.

EXPERIMENTAL RESULTS

The data on yield, lodging, and disease resistance for 1938 and 1939 are presented in Table 1. Both seasons were quite favorable for

corn in contrast to the 1934 and 1935 tests. The correlation between the yields of the 1934–35 and the 1938–39 tests was 0.162 which is not significant. On the assumption that yielding ability is determined chiefly by heredity this failure in agreement may be due to a high strain $\times$ season interaction or may be related to the top-cross parents used. If these parents differ widely in the dominant favorable factors they contribute to their top-cross progeny, correlations might reasonably be expected to be low.

In the 1934–35 trials the yield of B1 345 top crossed by Krug was essentially the same as the Krug parent. Similarly, in the 1938–39 comparisons, the yield of B1 345 top crossed by synthetic 8037 was not significantly different from the 8037 parent. In the 1938 and 1939 tests the synthetic 8037 outyielded the variety Krug by 8.9 bushels. Thus, in both cases, it appears that the line B1 345 may be low yielding and its inherent combining ability at least partially masked by the more favorable genes contributed by the top-cross parents. This same situation may exist with respect to lodging and disease susceptibility though possibly to a lesser degree.

As mentioned previously, the experimental design used was an 8×8 triple lattice and in consequence all items were not equally confounded. This complicates the separation of the variance associated with the F_3 families and the F_4 lines. Approximate solutions were tried, but in some cases the F values obtained were close to the 5% level of significance. This indicated that a more rigorous analysis would be desirable, consequently the variance associated with the F_4 lines within F_3 families was determined by a least squares solution. The F values were 1.34, 2.05, and 2.49 for the 1938, 1939, and the two-year average, respectively. (The writers are indebted to Prof. W. R. Cochran for this analysis.) These values indicate that segregation for top-cross combining ability was not significant in 1938 but was significant for the 1939 and the combined 1938–39 data, the probability exceeding the 1% point. These findings are in accord with the calculations made by Jenkins (2); however, it should be noted that the differences among F_3 family means are large compared with the differences among F_4 families. Selection among F_3 families thus would be more efficient than selection among F_4 lines.

LODGING

In both 1938 and 1939, lodging was due principally to stalk breaking but some root lodging was noted. Root and stalk lodging values were combined for the study of segregation. The data were analyzed as randomized complete blocks. For the 1938 tests the F values for F_3 families and F_4 lines within families were 16.80 and 3.65, respectively. The corresponding values for 1939 were 18.07 and 3.9. All of these values are highly significant, indicating that even in F_4 the lines were not homozygous for factors affecting strength of stalk. The indicated segregation was greater in F_3 than in F_4, as would be expected.

DAMAGED KERNELS

In 1938 the samples saved for damaged kernel determinations were composites of all replications and hence not suited for a study of

TABLE 1.—*Acre yield of ear corn in bushels, percentage of plants erect, and percentage of damaged kernels of 60 F_4 lines and their inbred and top-cross parents for the two-year period 1938 and 1939.*

Pedigree	1938				1939			
	Yield per acre, bu.		Erect plants %	Damaged kernels, %	Yield per acre, bu.		Erect plants %	Damaged Kernels, %
	F_4 lines	F_3 families			F_4 lines	F_3 families		
Krug	78.7	—	83.6	2.0	86.4	—	77.6	—
8037	89.4	—	96.1	0.8	93.5	—	85.6	—
L317×8037	94.4	—	95.6	0.3	98.7	—	87.9	—
B1 345×8037	87.5	—	88.4	1.6	91.4	—	72.0	—
L317×B1345-1-52-1×8037	92.2	—	91.6	2.7	106.3	—	80.6	13.4
-1-52-2×8037	97.1	—	96.3	1.6	102.1	—	88.2	11.1
-1-52-3×8037	96.6	—	91.3	4.0	107.2	—	91.2	6.3
-1-52-4×8037	93.6	—	96.9	3.0	99.0	—	91.1	9.0
-1-52-5×8037	92.6	95.1	92.6	0.7	107.1	104.3	89.2	10.4
-1-11-1×8037	93.9	—	65.0	3.9	102.8	—	66.0	8.9
-1-11-2×8037	89.9	—	87.3	0.8	99.2	—	85.4	9.4
-1-11-3×8037	91.5	—	93.8	0.5	93.4	—	88.8	3.4
-1-11-4×8037	98.3	—	91.9	1.1	96.1	—	77.2	14.2
-1-11-6×8037	91.3	93.0	91.4	0.2	92.2	96.6	78.0	5.7
-1-48-1×8037	101.0	—	93.3	2.0	103.4	—	90.2	14.2
2×8037	95.8	—	90.4	1.9	97.4	—	80.4	13.3
3×8037	95.6	—	91.3	1.2	100.4	—	86.7	7.6
4×8037	97.3	—	66.6	3.5	107.6	—	56.3	13.8
5×8037	96.7	97.3	71.2	2.7	103.1	102.4	69.4	12.9
-1-51-1×8037	101.3	—	92.2	1.3	108.8	—	74.8	11.7
-1-51-2×8037	94.9	—	91.9	1.8	101.5	—	79.5	8.7
-1-51-3×8037	97.0	—	93.9	1.7	109.3	—	86.5	6.8
-1-51-4×8037	97.9	—	98.0	5.2	98.9	—	91.2	21.3
-1-51-4×8037	99.4	98.1	94.2	6.0	99.6	103.6	86.9	23.7
-1-46-1×8037	102.2	—	93.3	2.0	111.7	—	84.7	9.2
-1-46-2×8037	96.7	—	86.2	1.2	108.6	—	78.4	9.9
-1-46-4×8037	95.8	—	95.0	0.3	109.2	—	73.3	8.2
-1-46-5×8037	94.0	—	93.8	1.7	103.2	—	71.8	3.9
-1-46-6×8037	96.8	97.1	92.7	1.2	106.5	107.8	64.2	6.7

-I-39-I×8037	102.3	—	91.1	0.3	101.1	—	70.8	11.8
-I-39-2×8037	98.5	—	84.9	0.4	102.5	—	75.6	1.8
-I-39-3×8037	98.5	—	83.0	1.3	103.8	—	63.2	6.4
-I-39-4×8037	91.5	—	93.2	1.4	99.6	—	72.1	9.7
-I-39-5×8037	96.2	97.4	83.1	0.2	96.7	100.7	66.4	7.5
-I-59-I×8037	94.9	—	92.1	0.6	103.2	—	82.3	16.0
-I-59-2×8037	97.8	—	88.9	1.7	96.3	—	76.5	26.5
-I-59-3×8037	100.3	—	95.8	0.4	105.3	—	81.2	23.4
-I-59-6×8037	95.9	—	85.5	0.2	98.9	—	65.3	17.9
-I-59-7×8037	96.9	99.2	90.2	1.8	107.8	102.3	74.8	25.4
-I-66-I×8037	95.1	—	93.2	1.6	100.1	—	72.0	15.4
-I-66-2×8037	93.5	—	96.9	1.6	105.3	—	84.0	19.3
-I-66-3×8037	88.9	—	84.5	0.4	96.7	—	65.0	12.8
-I-66-4×8037	95.3	—	86.3	1.0	99.0	—	63.3	11.1
-I-66-5×8037	88.3	92.2	85.7	2.9	94.8	99.2	65.2	13.2
-I-62-I×8037	92.7	—	93.6	1.2	98.6	—	74.1	18.9
-I-62-2×8037	92.9	—	95.5	0.8	101.4	—	91.2	27.4
-I-62-3×8037	89.0	—	98.9	1.4	98.8	—	93.7	9.1
-I-62-6×8037	95.0	—	99.4	1.9	98.6	—	92.6	13.7
-I-62-7×8037	92.9	92.5	88.8	2.7	98.9	99.3	73.6	20.4
-I-23-I×8037	98.8	—	79.7	1.6	105.7	—	58.6	11.7
-I-23-2×8037	97.0	—	78.6	1.1	103.8	—	69.5	17.5
-I-23-3×8037	93.5	—	60.4	2.0	102.8	—	35.9	13.7
-I-23-4×8037	98.7	—	73.4	3.1	100.4	—	67.0	17.3
-I-23-5×8037	97.1	97.0	84.3	0.9	101.7	102.9	60.6	15.4
-I-44-I×8037	95.8	—	96.6	1.7	102.2	—	90.8	15.9
-I-44-2×8037	101.5	—	96.1	0.9	109.7	—	86.2	10.6
-I-44-3×8037	94.0	—	99.4	3.0	104.5	—	93.5	13.6
-I-44-4×8037	101.1	—	97.5	0.7	106.5	—	80.8	4.9
-I-44-5×8037	95.0	97.5	96.6	1.9	100.1	104.6	74.8	6.3
-I-64-2×8037	98.4	—	92.5	1.7	101.8	—	74.9	11.4
-I-64-3×8037	94.4	—	91.4	0.8	96.3	—	68.3	12.8
-I-64-5×8037	99.9	—	96.4	3.1	102.0	—	75.3	14.0
-I-64-6×8037	97.5	—	93.1	2.1	104.7	—	86.5	10.5
-I-64-7×8037	107.4	99.5	96.1	1.8	112.4	103.4	79.2	11.3

segregation. In 1939 separate samples were saved from three of the six replications. These samples were obtained by shelling the corn from an entire plot. This sample was then reduced to the desired size by running through a Boerner sampler. The separation for damaged kernels was made according to the Official Grain Standards. Due to damage by mice, samples from six plots were omitted from the analysis. This left an unequal number of observations in the various classes and the data were analyzed accordingly. The F values for the F_3 families (11DF) and the F_4 lines within F_3 families (48DF) were 8.05 and 1.57, respectively. The first of these values is highly significant and the second is significant using odds of 20:1. This indicates that at least some of the lines were still heterozygous for factors affecting the relative resistance to kernel rots.

DISCUSSION

With the exception of the 1938 yield data, all of the variables studied indicated that detectable segregation had occurred among the various F_4 lines tested. This emphasizes one problem facing the corn breeder for which no final answer is yet available, namely, Should inbreeding be continued until lines are stable before starting the testing program or should testing be done at the time inbreeding is started? In the latter event, segregation will occur and in consequence performance tests at this stage may not entirely represent the performance of the particular substrains which will be isolated after further inbreeding. Arguments can and have been advanced for both methods and both are being used to some extent. It has been the general practice, however, to test new inbred lines in top-cross combinations after three or four generations of inbreeding. This practice is intermediate between the two extremes just cited.

Jenkins (2) and Sprague (3) have advocated early testing of new inbreds, either testing the original plant at the time inbreeding is begun or testing after one or two generations of selfing. The main advantages which may be claimed for early testing are that (a) plants grown from open-pollinated seed differ widely in their inherent yielding ability and (b) the effectiveness of selection is greatest among the original plants and decreases with each generation of selfing. Rigorous selection for visible characteristics has been shown to have little effect on combining ability (1). With the system of testing commonly practiced, the lines saved after three or four generations of inbreeding represent a random sample of the combining ability of the parent variety or hybrid. After the first top-cross test of such material, it is usually found that many lines have low combining potentialities and must be discarded. The time and labor spent in selfing such material is wasted. With early testing the lines with high hybrid combining ability are identified the year following the first selfing. This material may then be grown in larger progenies than would be feasible with material whose performance was unknown. Larger progenies from which to select during further inbreeding should increase the efficiency of selection for the various plant, ear, and kernel characteristics which are essential to inbred lines used commercially.

In the early testing which has been done thus far, yield has received the major attention. In three experiments involving selected plants from an open-pollinated variety which were selfed and crossed with a common tester, the range in yields was as follows: Experiment 1, 101.4 to 63.8 bushels; experiment 2, 86.3 to 57.7 bushels; and experiment 3, 96.5 to 62.0 bushels. These differences in potential yielding ability among selected plants are considerable. Additional experiments are now under way to answer two questions, namely, (a) to what extent will these differences in yielding ability persist, i.e., to what extent have they been obscured by the yielding ability of the top-cross parent, and (b) how effectively will a series of top-cross parents specifically selected for various weaknesses combine early testing for yielding ability with such other important characters as stalk strength, tendency to drop ears, etc. Preliminary answers to these questions should be available from experiments now in progress.

The objections to early testing which have been raised most frequently are (a) the possibility of the loss of lines due to undesirable agronomic characters and (b) the high cost of testing. It is undoubtedly true that some lines homozygous for undesirable plant or seedling types may be discarded after the expense of testing them has been incurred. However, in many cases when segregations occur the undesirable types may be eliminated by selection. Segregations which produce a less pronounced visual effect, such as the ones reported here, will not be elminated by the customary three or four generations of selfing before top crossing. In these respects at least the difference between ordinary methods of testing and early testing is one of degree rather than of kind.

Little information is available relative to the second objection—cost of testing. On the basis of the limited comparative data now available there is no essential difference in cost between the two methods. This problem is a local one and must be decided by each worker on the basis of local conditions.

SUMMARY

Seventy-three F_3 lines from the single-cross L 317 × B1 345 were top crossed by the variety Krug and tested for yield, lodging, and damaged kernels in 1934 and 1935. Highly significant differences in top-cross yields were obtained.

From this group, 12 F_3 families were selected for further study on the basis of their top-cross performance. After an additional year of selfing, five F_4 ears were chosen to represent each F_3 family. The F_4 lines were top crossed by the synthetic hybrid 8037 and tested in yield trials in 1938 and 1939.

The data obtained indicated that significant segregations occurred among the F_4 lines for yield prepotency, lodging, and disease resistance. The bearing of these results on early and late testing of inbred lines is discussed.

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CORRELATED STUDIES OF WINTERHARDINESS AND RUST REACTION OF PARENTS AND INBRED PROGENIES OF ORCHARD GRASS AND TIMOTHY[1]

W. M. Myers and S. J. P. Chilton[2]

IN perennial pasture plants the ability to survive during severe winters is a characteristic of great importance. With orchard grass winterhardiness is a limiting factor in the northern distribution of the species. In the winter of 1939–40, severe winter injury occurred in individually spaced plants of orchard grass and timothy in the grass nursery of the U. S. Regional Pasture Research Laboratory, State College, Pa., and this afforded opportunity to select for this character. Since the severe winter was preceded by a natural epiphytotic of *Puccinia graminis* in the orchard grass and of *Puccinia phlei-pratensis* in the timothy during the summer of 1939, it was possible to determine whether rust injury had any effect on winter survival and spring recovery. It is the purpose of this paper to report these results since nothing was found in the literature bearing directly on this subject.

LITERATURE REVIEW

Differential winterhardiness of strains of orchard grass is known to occur, but the authors do not know of any report of studies of differences in winter hardiness of individual plants and of the inheritance of those differences either in orchard grass or timothy.

Stem rust of timothy has been reported as a destructive disease by several workers. Horsfall (5)[3] has reviewed the literature on economic importance, classification, and range of this disease. Clark (2) noted variations in degree of resistance of plants of timothy to stem rust, and Hayes and Stakman (4) reported that some Cornell selections of timothy has high percentages of resistant plants. Barker and Hayes (1) found that resistance was dominant and conditioned by a single factor. According to Horsfall (5), Proytchoff obtained similar results but also had evidence of modifying factors.

Radulescu (6, 7) found that rust-resistant clones of timothy were superior to susceptible clones in early spring growth, recovery following clipping and total yield.

MATERIALS AND METHODS

Sixty parental clones of timothy and their first generation inbred progenies and 59 clones of orchard grass and their inbred progenies were available for study. The plants were spaced 18 inches apart in rows 15 feet long and 3 feet apart. The 10 plants of the first row were from an inbred progeny, the parental clone of which occupied the first five spaces in the adjacent row. The next five spaces in this second row were planted with another parental clone, the inbred progeny of which was planted in the third row. This method of planting was continued

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[2]Geneticist and formerly Agent, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 220.

throughout the nursery and all clones and their adjacent inbred progenies were distributed at random in three replications. Such a method of planting is effective where critical parent-progeny comparisons of plant type, disease reaction, and other characters are desired.

The individual plants of each clone and each inbred progeny were classified for rust reaction and for winter injury. The following rust classes were used:

- 0 = no pustules and no evidence of rust infection.
- 1a = Flecks or small, round pustules sometimes surrounded by necrotic areas. One to a few pustules per leaf.
- 2a = Pustule type as in la but numerous pustules on some leaves.
- 3a = Pustule type as in la but with many pustules on most leaves.
- 1 = Pustule frequency similar to 1a but the pustules large and particularly elongated.
- 2 = Pustule frequency similar to 2a but with type of pustule like 1.
- 3 = Pustule frequency similar to 3a but with type of pustule like 1.
- 4 = Pustule type like 1 but with the pustules on many leaves so numerous that parts or all of one or more of the leaves were killed.
- 5 = Pustule type like 1 but injury more severe than in 4, so that all of the leaves were killed.

In classifying for winter survival, a combined estimate of the amount of dead plant material and recovery of growth on May 10 was made. Similar classes were used for orchard grass and timothy except that in timothy it was necessary to place more emphasis on vigor of recovery in the spring, as the leaves made but little growth during the previous fall. The classes were as follows:

- 1 = no apparent killing of top growth. Very vigorous and rapid recovery.
- 2 = some killing of top growth and vigorous recovery, although some-what less than 1. In orchard grass, about one-fourth of the top growth was dead.
- 3 = more severe killing and slower recovery than in 2. About three-fourths of the top growth was dead in orchard grass.
- 4 = no evidence of spring growth at the time of note taking. Most of these plants were dead. Occasionally plants classified as 4 later produced a few leaves, but the plants were weak and abnormal.

EXPERIMENTAL RESULTS

HERITABLE VARIATIONS IN WINTER INJURY

The data on winter injury of the parental clones of orchard grass are given in Table 1. The column headings indicate the classes in which different plants of the clone were placed and the numbers in the columns show the number of clones with plants in the particular class or classes. In 11 clones all plants were placed in classes 1 and 2 (none to ¼ of the top growth dead but very vigorous to vigorous recovery in the spring), while at the other extreme in three clones all plants were placed in class 4 (no evidence of spring growth at the time the notes were taken and most plants dead). The remaining 45 clones were intermediate between these extremes. In timothy (Table 2) a similar range in variation occurred, two clones having all plants in class 1 and four clones having all plants in classes 3 and 4. An analysis of variance (Table 3) showed that in both species the differences among clones were highly significant statistically, the value F being in excess of the value of F for P of 0.01 (8).

TABLE 1.—*Relation of winter injury of parental clones and their first inbred generation progenies in orchard grass.*

Inbred reaction	Clonal reaction						
	1–2	2	2–3	2–3–4	3–4	4	Total
1–2	3	2	–	–	–	–	5
1–2–3	6	3	3	–	–	–	12
1–2–3–4	2	1	4	–	–	–	7
2	–	–	–	–	–	–	–
2–3	–	1	1	–	–	–	2
2–3–4	–	1	14	2	4	1	22
3	–	–	–	–	–	–	–
3–4	–	–	–	2	6	1	9
4	–	–	–	–	1	1	2
Total	11	8	22	4	11	3	–

r = 0.905.

TABLE 2.—*Relation of winter injury of parental clones and their first inbred generation progenies in timothy.*

Inbred reaction	Clonal reaction									
	1	1–2	2	1–2–3	2–3	1–2–3–4	3	2–3–4	3–4	Total
1–2	1	–	–	–	–	–	–	–	–	1
1–2–3	1	6	1	–	3	–	–	–	–	11
2–3	–	–	–	–	–	–	–	1	–	1
1–2–3–4	–	6	3	5	2	1	–	1	–	18
2–3–4	–	–	2	2	13	–	1	5	2	25
3–4	–	–	–	–	1	–	–	1	1	3
4	–	–	–	–	–	–	–	–	1	1
Total	2	12	6	7	19	1	1	8	4	–

r = 0.849.

TABLE 3.—*Analysis of variance of winter injury of parental clones of orchard grass and timothy.*

Variation due to	D/F	Mean square	F
Orchard Grass			
Replications	2	0.512516	4.476
Clones	58	1.650445	14.416*
Error	116	0.114497	
Timothy			
Replications	2	0.381100	2.485
Clones	59	1.217828	7.940*
Error	118	0.153371	

*Exceeds value of F for P of 0.01.

The data in Table 1 and 2 are arranged to show the relationship of the winter injury of the inbred progenies to that of their respective parental clones. For example, in Table 1, three parental clones of orchard grass in which all plants were placed in classes 1 and 2 had inbred progenies, all plants of which were likewise classified as 1 or 2. Examination of these tables reveals in both species that the reactions of inbred progenies were similar to their parental clones. A striking example of this in orchard grass is illustrated in Fig. 1. The correlation coefficient of the means of the three replications of the parental clones with the means of the inbred progenies was 0.905 in orchard grass and 0.849 in timothy. These values are greatly in excess of r for P of .01 (3). The results indicate that heritable differences in resistance to winter injury occur in this material.

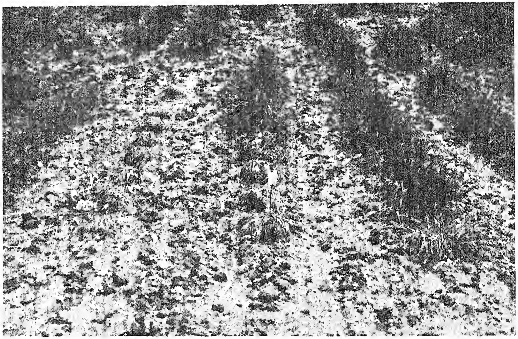

FIG. 1.—Variation in winter injury in clones and their inbred progenies of orchard grass. The row on the left is the first inbred generation progeny of the parental clone in the foreground of the center row, while the row on the right is the first inbred generation progeny of the parental clone in the background of the center row.

In each species, some of the inbred progenies contained only the reaction classes that were found in the parental clones. In other progenies, clear-cut segregation occurred (Fig. 2). In some of these cases the segregates showed less winter injury than the parent, but more commonly the segregation was in the direction of greater winter injury. It is not possible to draw any conclusions from these data regarding the number of genetic factors involved in conditioning this character. Nevertheless, it seems probable that selection for resistance to winter injury will be effective.

RELATION OF WINTER INJURY TO RUST REACTION

The absence of any relationship of winter injury to rust reaction among the parental clones of orchard grass is shown in Table 4.

These data were combined in a 2 × 2 table to increase the numbers in each class and X^2 for independence calculated. It was found to be 0.193, a non-significant value (3).

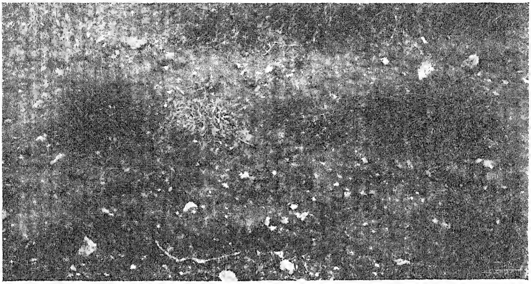

FIG. 2.—Segregation for winter injury among plants of a first inbred generation progeny of orchard grass.

TABLE 4.—*Relation of winter injury to rust reaction of parental clones of orchard grass.*

Rust reaction	Winter injury						
	1–2	2	2–3	2–3–4	3–4	4	Total
0–1a	3	3	9	1	5	3	24
1–1.9	6	3	12	2	6	–	29
2–2.9	2	2	1	1	–	–	6
Total	11	8	22	4	11	3	59

In timothy, stem rust appears to have been an important factor contributing to winter injury (Table 5). The data in Table 5 were combined into a 2 × 2 table and X^2 for independence calculated. A value of 21.60 was obtained, which is greatly in excess of X^2 for the 1% point. The apparent inconsistency of the differential effects of stem rust injury on winter injury in the two species may probably be attributed in part to the severity of the rust epiphytotic. The epiphytotic started first in the timothy nursery and the timothy plants were much more severely attacked, many plants being placed in class 5. On the other hand, only a few plants of orchard grass were classed as 3 and none were higher.

SUMMARY

Statistically significant differences in winter injury were found between 59 parental clones of orchard grass and between 60 parental clones of timothy.

TABLE 5.—*Relation of winter injury to rust reaction of parental clones of timothy.*

Rust reaction	Winter injury									
	1	1–2	2	1–2–3	2–3	1–2–3–4	3	2–3–4	3–4	Total
1a–2a . . .	–	–	1	–	–	–	–	–	–	1
3a.	1	1	–	–	–	–	–	–	–	2
1–2–3. . . .	–	–	–	1	–	–	–	–	–	1
3.	1	1	1	–	1	–	–	–	–	4
2–3–4. . . .	–	1	–	–	1	–	–	–	–	2
3–4.	–	7	4	3	4	–	–	1	–	19
3–4–5. . . .	–	–	–	–	6	–	–	3	–	9
4.	–	1	–	–	1	–	–	–	–	2
4–5.	–	1	–	3	5	1	1	4	4	19
5.	–	–	–	–	1	–	–	–	–	1
Total. . . .	2	12	6	7	19	1	1	8	4	60

The correlation coefficients of the mean winter injury of the parental clones and their inbred progenies were 0.905 and 0.849, respectively, in orchard grass and timothy. Segregation occurred within inbred progenies suggesting the possibility of selecting for resistance to winter injury both within and between inbred progenies.

Severity of stem rust infection was correlated with degree of winter injury in the parental clones of timothy. No similar association was found in orchard grass.

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FACTORS AFFECTING COLD RESISTANCE IN WINTER WHEAT[1]

W. W. WORZELLA AND G. H. CUTLER[2]

THE annual abandonment of winter wheat acreage in the Middle West varies widely from year to year. Data compiled by Bayles and Taylor (2),[3] involving the 28-year period from 1909 to 1937, reveal a loss of 1% in some winters to as high as 60% in others, with an average of about 10%. They also state that "the losses caused by winterkilling in the soft red winter region are probably greater than the combined losses from all plant diseases."

Winter injury to the wheat plant may be caused by cold temperatures, heaving, and smothering. Because of the severity of this problem, experiments have been conducted to determine some of the basic causes and factors affecting winterkilling in wheat in Indiana. The present paper reports the results of a series of tests designed to study the effect of stage of development, hessian fly infestation, fertility levels, and prevailing weather conditions during the fall and winter months on cold resistance in winter wheat.

MATERIALS AND METHODS

Six varieties of wheat having a wide range in winterhardiness were used. These varieties were in order of ascending hardiness, Redhart, Poole, Michigan Amber, Michikof, Kanred, and Minhardi. In addition, 30 varieties and 189 hybrid strains were employed in studying the correlation between results of artificial freezing and field tests.

Field-hardened seedlings were used in all artificial freezing tests. The seedlings were grown in soil-filled wooden flats 15×22×4 inches and 4-inch clay pots, which were placed side by side in a shallow excavation in the field so that their tops were level with the soil surface. Plantings were made during the last part of September or the first few days in October at the normal field seeding date. In the flats, the seed was sown at half-inch intervals in rows 2 inches apart with 10 rows per flat. Seven seeds were planted in each pot to insure a uniform stand of five plants. The soil in the flats and pots was kept well watered and the seedlings remained under field conditions until subjected to the artificial freezing tests at different intervals throughout the winter.

The artificial freezing equipment used in these tests was described earlier by Worzella (12). Wheat seedlings grown in pots were frozen at 0°F for 8 hours (8 a.m. to 4 p.m.) and those in flats were subjected to temperatures of −5°F to −12°F for a period of 24 hours (8 a.m. to 8 a.m.). Eight flats or 50 pots, containing at least 50 seedlings of each variety and variant, were frozen during each test. Immediately after freezing the seedlings were transferred to the greenhouse, the air temperature of which was maintained at about 60°F, and kept well watered in an attempt to revive them. Ten days after freezing the amount of injury was

[1]Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Ind. Also presented before the annual meeting of the Society held in Chicago, Ill., December 4 to 6, 1940. Received for publication December 6, 1940.

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[3]Reference by number is to "Literature Cited", p. 229.

estimated and recorded as percentage estimated survival. Coefficients of correlation and differences necessary for significance between two means were calculated to aid in the interpretation of the data.

EXPERIMENTAL RESULTS

RELATION BETWEEN RESULTS OF ARTIFICIAL FREEZING AND FIELD TESTS

In order to determine the usefulness of the artificial freezing test for measuring winterhardiness in wheat, comparable tests were conducted under artificial and field conditions. Field winter survival data were obtained at Lafayette, Ind., during the 5-year period 1933 to 1937 on 30 varieties of wheat. These varieties, representing those grown in the uniform eastern winterhardiness nurseries and known to vary widely in cold resistance, were also subjected to artificial freezing tests. In addition, 189 hybrid strains were subjected to freezing tests during the winters of 1935–36 and 1936–37. The correlation coefficients between results of artificial freezing and field tests are shown in Table 1.

TABLE 1.—*Correlation between results of artificial freezing and field tests for measuring cold resistance in winter wheat.*

Correlation between	Number of strains or varieties	Correlation coefficient
Field results and artificial tests	30	+0.73*
1935–36 and 1936–37 artificial tests	30	+0.95*
1935–36 and 1936–37 artificial tests	189	+0.66*

*Exceed the 1% level of significance.

A very good agreement was found between the field results and artificial freezing tests as indicated by the highly significant correlation coefficient +0.73. Also, the freezing tests conducted for two seasons show a high order of agreement, especially with varieties varying widely in cold resistance. The data indicate that the artificial freezing test is a reliable tool in appraising the relative cold resistance of wheats. These results confirm the finding of other investigators, especially those of Martin (6), Quisenberry (7), and Salmon (8).

EFFECT OF SNOW AND ICE COVER ON SOIL TEMPERATURES AND INJURY TO WHEAT

In studying the effect of snow and ice cover on soil temperatures and injury to wheat, continuous soil and air temperatures were recorded under field conditions during the winter months. Also, a record was kept of the amount of snow or ice cover present throughout the winter period. Two recording thermometers were used to register the air temperatures as well as the soil temperatures ½ inch below the surface. At regular intervals during the winter months field-grown wheat seedlings, representing 10 pots of each of the varieties Redhart, Poole, Michigan Amber, Kanred, and Minhardi,

were brought into the greenhouse. These were well watered and allowed to revive for about 10 days at which time the amount of injury caused by the field exposure was estimated.

Winterhardiness data obtained under field conditions are influenced by many uncontrollable ecological conditions and often it is difficult to isolate the factor or factors causing winter injury. Abnormal seasons that exhibit extremes in temperature, snow cover, and ice sheet, usually furnish the most useful data for this type of study. The winter of 1935–36 in Indiana was very severe, resulting in about 40% winter injury to the wheat crop in the Lafayette area. Fig. 1 graphically shows the air and soil temperatures and also the snow cover and ice layer during January and February 1936, while Table 2 indicates the estimated winter survival of the five wheat varieties during this same period.

TABLE 2.—*Estimated winter survival of wheat seedlings exposed to field conditions until January and February 1936 at Lafayette, Ind.*

Variety	Average estimated survival, %				
	Jan. 16	Jan. 28	Feb. 10	Feb. 17	Feb. 24
Redhart	0	0	3	0	0
Poole	74	74	39	29	2
Michigan Amber	94	84	61	55	18
Kanred	100	90	83	70	40
Minhardi	100	94	94	83	79

Results in Fig. 1 show that during the period of the lowest atmospheric temperatures the ground was covered with 4 to 5 inches of snow. On February 4, due to a rain, the snow melted and then froze to form a 2-inch layer of ice that remained on the ground for 3 weeks. While the ground was covered with snow, the soil temperatures showed little variation but gradually lowered; however, a close asso-

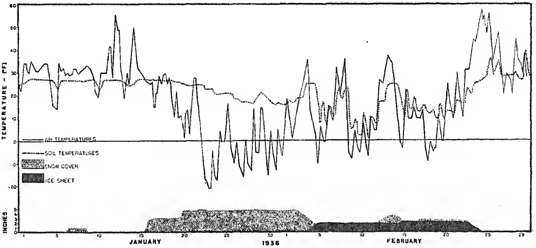

FIG. 1.—Effect of snow cover and ice sheet layer under field conditions on soil temperatures during January and February 1936 at Lafayette, Ind.

ciation is noted between the temperature of the soil under a layer of ice and the prevailing atmospheric temperatures. Also, soil protected by snow, even though exposed to much lower air temperatures, remained warmer than that under an ice sheet. On January 23, the temperature of the snow-protected soil was +23°F, while that of the air was −21°F, or a difference of 44°F; whereas, on February 11, the temperature of the ice-covered soil was +1°F and of the air −7°F, or a difference of only 8°F. The winter injury to the wheat crop in the Lafayette area was not the result of the unusually low temperatures during January but rather those in February, as shown in Table 2. Except for Redhart, a very tender wheat, only the tips of the leaves of the varieties had been injured prior to January 28. During the next two weeks, the more tender varieties Poole and Michigan Amber showed considerable winter injury with survival estimates on February 10 of 39% and 61%, respectively. The survival data obtained during the following two weeks represent the cumulative injury up to this period and indicate that all varieties, except Minhardi, were badly winterkilled. The lower soil temperatures of February, especially on February 9, 10, and 11, seem to have caused the winter injury. Tests, yet incomplete, indicate that temperatures of 0° to +5°F appear to be lethal to well-hardened wheat seedlings.

EFFECT OF WEATHER CONDITIONS ON FIELD HARDENING AND COLD RESISTANCE IN WINTER WHEAT

In order to determine the effect of prevailing weather conditions on field hardening and relative cold resistance in wheat varieties, field-grown seedlings were subjected to artificial freezing tests at regular intervals during the 5-year period 1931–32 to 1935–36. Some 1,250 pots, containing seedlings of the varieties Poole, Michigan Amber, Michikof, Kanred, and Minhardi, were grown in the field for this study. Except for the first year, the tests were conducted each week through the winter months. Different sets of 10 pots of each variety were brought in from the field and subjected to a uniform freezing test of 0°F for 8 hours produced in a cold chamber.

In order to simplify the presentation of these results and because the varieties reacted much the same during each of the five years, the survival data for the five varieties were averaged. However, to show the effect of the weather conditions on the behavior of the individual varieties, the data for the five varieties are reported separately only for the 1932–33 season. The relative cold resistance and behavior of winter wheats during the winter months, as affected by weather conditions—especially atmospheric temperatures, are presented graphically in Figs. 2 and 3.

The results in Figs. 2 and 3 show that variations in level of hardiness occurred from week to week, season to season, and among varieties. The data indicate that the atmospheric temperatures which prevailed several days prior to the freezing test greatly affected the ability of the wheat plants to resist low temperatures. In general, a negative relationship exists between atmospheric temperatures and winter survival. That is, when the atmospheric temperatures lowered, the wheat plants became hardened and possessed greater cold re-

sistance, but when the weather became warmer they lost their hardiness and became rather tender. This process of acquiring and losing winterhardiness recurs repeatedly during the winter months, depending upon prevailing atmospheric temperatures. The level of hardiness in wheats also varies from year to year. For example, during the mild winters of 1931–32 and 1934–35, the wheats were tender; however, during the severe winter of 1935–36, they possessed a high degree of hardiness as reflected by the higher survival data obtained for the latter year. Similar trends have been reported by Anderson and Kiesselbach (1) and Suneson and Peltier (11).

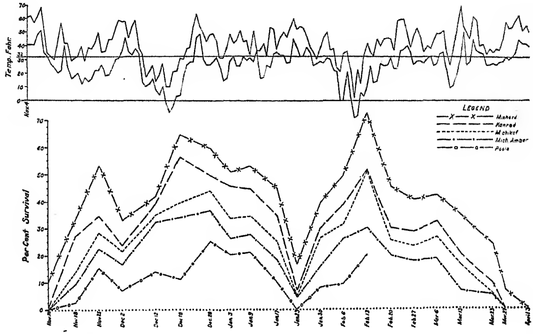

Fig. 2.—Winter survival of five varieties of wheat when different sets of seedlings were subjected to an 8 hour exposure of 0° F in a cold chamber, at weekly intervals during the winter months of 1932–33. The minimum and maximum daily temperatures also are shown.

The five varieties tested varied widely in their relative cold resistance throughout the winter season as shown in Fig. 2. The variety Minhardi not only possessed the highest level of cold resistance, but also was able to accumulate the greatest degree of hardiness during periods of cold temperatures, as shown by the increased spread in winter survival. Also, Minhardi acquired hardiness earlier in the fall and continued to remain in this condition later in the spring. Laude (5) reported that the variety Harvest Queen lost its resistance to cold more slowly in the spring than Kanred and Minturki. No change in varietal rank or reversal of varietal hardiness during the winter period was obtained with the five varieties used. Hill and Salmon (3) reported that the relative cold resistance of wheat varieties is dependent on the degree of hardening. Changes in the relative rank were noted by Anderson and Kiesselbach (1) and Suneson and Peltier (9) and were attributed to differential hardening adjustments to environmental conditions.

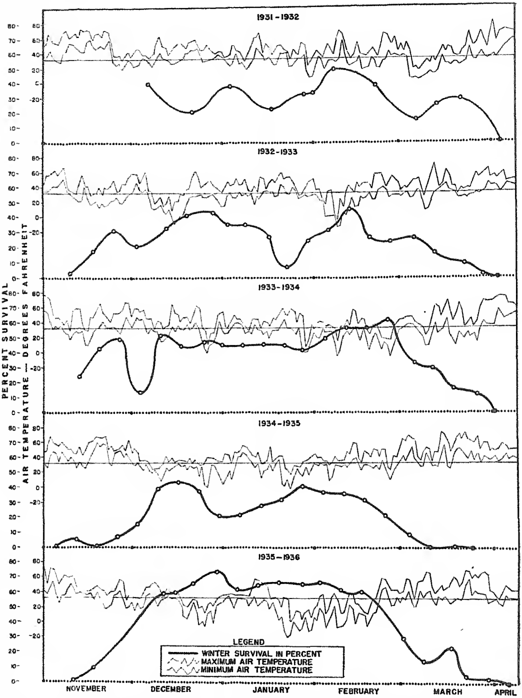

FIG. 3.—Average winter survival of wheat varieties when different sets of seedlings were given an 8-hour exposure at 0° F in a cold chamber at weekly intervals throughout the winter months of 1931–32 to 1935–36. The minimum and maximum daily temperatures also are shown during this 5-year period.

EFFECT OF STAGE OF DEVELOPMENT OF WHEAT SEEDLINGS ON COLD RESISTANCE

To determine the effect of stage of development of wheat seedlings on cold resistance, field plantings were made on September 15, October 1 and 15, and November 1 during each of four years. Since the growing seasons varied from year to year, the seedlings were grouped into five stages depending upon the number of leaves or

height of the plant. Eight flats, containing seedlings of five varieties of each stage, were subjected to the freezing tests at five separate periods during the winter months. The estimated average survival of the seedlings is shown in Table 3.

TABLE 3.—*Effect of stage of development of wheat seedlings on cold resistance.*

Year	Number of tests	Average estimated survival, %*				
		Germinated seed to coleoptile stage	Seedlings with 2 to 4 leaves	Seedlings with 5 to 9 leaves	Seedlings with 8 to 15 leaves	Seedlings 10 to 12 in. in height
1936–37	20	8.6	42.0	50.6	—	38.3
1937–38	15	5.3	11.5	30.7	†	—
1938–39	15	—	19.4	33.4	32.6	†
1939–40	20	—	21.8	39.6	42.6	19.3

*A difference of 3.2 is highly significant.
†Seedlings infested with hessian fly.

The data show that germinated seed or seedlings in the one-leaf or coleoptile stage are quite susceptible to cold. Wheat seedlings having two to four leaves show an increase in winter survival; however, those possessing from 5 to 15 leaves per plant are the most cold resistant. Wheat plants 10 to 12 inches in height are not as hardy as those possessing the usual fall growth. These data confirm the earlier findings of Worzella (12) but are in disagreement with the results of Suneson and Peltier (10). Working with greenhouse-grown seedlings, Suneson and Peltier report the youngest plants (4 days after emergence) to be the most cold resistant.

EFFECT OF LEVEL OF FERTILITY ON COLD RESISTANCE OF WHEAT SEEDLINGS

To determine the effect of level of fertility on cold resistance of winter wheat, seedlings grown on soil treated with different amounts of fertilizer and manure were subjected to artificial freezing tests. Using Warsaw silt loam soil, four fertility levels were made as follows: (a) Low, no treatment; (b) medium, 3.5 grams sodium nitrate (16% N), 3.5 grams muriate of potash (50% K_2O), and 7 grams superphosphate (20% P_2O_5) per flat containing about 70 pounds of soil; (c) high, 14 grams sodium nitrate, 14 grams muriate of potash, and 28 grams superphosphate; and (d) high manure, same as (c) plus 5 pounds of manure. The wheat plants appeared quite normal but showed great differences in top development. Those grown on the non-fertilized soil were small, while those on the high level of fertility showed rank growth. Eight flats, representing seedlings of five varieties grown on all fertility levels, were frozen at each of five periods during the winter months. The average survival data are given in Table 4.

It will be noted that, under the conditions of these experiments, wheat seedlings grown on low or medium levels of fertility differ little in their cold resistance. The seedlings grown on the high levels of fertility showed the greatest injury. Since soil fertility greatly in-

fluences plant development, which in turn affects cold resistance, it appears that the fertility of the soil has an indirect effect on cold resistance. That is, poor soils produce small seedlings while rich soils develop large succulent plants, resulting in stages of plant development that are susceptible to cold. Levels of fertility that result in a normal development of the wheat plant, or one possessing from 5 to 15 leaves, favor resistance to cold injury. Holbert (4) subjected to freezing temperatures corn plants grown on virgin and cropped soil as well as fertilized and unfertilized soil. His data show that the corn plants grown on the more productive soil were more cold resistant. However, no attempt was made to relate the effect of variations in the stage of plant development caused by the treatments with cold injury.

TABLE 4.—*Effect of level of fertility on the cold resistance of wheat seedlings.*

Year	Number of tests	Average estimated survival, %*			
		Low level	Medium level	High level	High level plus manure
1936–37	15	42.3	46.7	43.1	—
1937–38	15	30.7	30.8	29.4	—
1938–39	20	51.3	52.0	40.8	35.3
1939–40	20	43.0	50.3	39.2	31.4

*A difference of 3.2 is highly significant.

EFFECT OF FALL HESSIAN FLY INFESTATION ON COLD RESISTANCE OF WHEAT SEEDLINGS

To determine the effect of hessian fly infestation on cold resistance of wheat seedlings, field-grown infested and non-infested plants were subjected to freezing tests. Three weeks after planting one-half of each flat, containing seedlings of five varieties, was exposed to hessian fly infestation by releasing flies on the plants in fly-proof wire cages. After the plants were infested, the cages were removed from the plants. During the winter months they were subjected to a regular freezing test. Ten days after freezing each plant was dug, examined, and record made of its fly infestation and winter survival. The average survival data of infested and non-infested plants are given in Table 5.

The results in Table 5 show that the wheat plants of five varieties infested with hessian fly were very susceptible to freezing temperatures.

SUMMARY

All studies dealing with factors affecting cold resistance in winter wheats were conducted with field-hardened plants. Varieties of wheat, varying widely in winterhardiness, were grown in 4-inch pots or flats in the field and were subjected to controlled freezing tests at regular intervals throughout the winter months. Continuous soil and air temperatures under field conditions were recorded.

TABLE 5.—*Effect of fall hessian fly infestation on cold resistance of wheat seedlings.**

Year	Infested seedlings		Non-infested seedlings	
	Number of plants	Average winters survival, %	Number of plants	Average winters survival, %
1936–37..........	218	14.4	201	50.8
1937–38..........	550	4.7	111	26.0
1938–39..........	91	7.9	108	50.3

*In cooperation with W. B. Noble and W. B. Cartwright of the Bureau of Entomology and Plant Quarantine, U. S. D. A.

A good agreement was found between results of artificial freezing and field tests.

The temperature of the soil under a layer of ice was found to be closely associated with atmospheric temperatures. Soil protected with 3 to 5 inches of snow showed small changes in temperatures. A spread of 44° F was recorded between the temperatures of the air and snow-covered soil. Ice-covered soil reached lower temperatures than that covered with a layer of snow.

Wheat plants repeatedly acquire and lose their hardiness, depending upon the atmospheric temperatures during the winter months. Variations in level of hardiness were found from week to week, season to season, and among varieties. Wheats vary in their degree of cold resistance, ability to accumulate hardiness, and to acquire the hardened condition earlier in the fall and retain it later in the spring.

Wheat seedlings possessing from 5 to 15 leaves per plant were the most cold resistant. Germinated seed to seedlings with two to four leaves and plants 10 to 12 inches tall were quite susceptible to cold.

Under the conditions of these experiments, wheat seedlings grown on low and medium levels of fertility differ little in their cold resistance. The seedlings grown on high levels were large and succulent and showed the greatest injury. Since soil fertility greatly influences plant development, which in turn affects cold resistance, it appears that the fertility of the soil has an indirect effect on cold resistance.

Wheat plants of five varieties infested with hessian fly were more susceptible to freezing temperatures than non-infested plants.

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THE EFFECT OF PHOTO-PERIOD ON THE GROWTH OF LESPEDEZA[1]

GEO. E. SMITH[2]

KOREAN lespedeza has become a most important crop in Missouri (2).[3] It is grown with varying degrees of success in all regions of the state, although the acreage is much larger in some areas than in others. Because of variable response on different soils that could not always be correlated with different fertility levels, attention has been given by trials, both in field and greenhouse, to the effects of different soil treatments and of different nutrients on its growth.

When greenhouse plantings were made in mid-winter, the growth of lespedeza was slow. Seeds appeared on the plants in six to seven weeks and when they were only about 2 inches high. Such plants matured seed and died without further growth. The greenhouse temperature ranged between 60° F at night and 80° F during the day, which is not widely different from that in the spring when lespedeza is making satisfactory growth in the field. During the winter the length of the daylight period is short, hence it was believed (6) that the lack of a sufficient day length might be responsible for this early fruiting. Experimental trials were undertaken to test the validity of this belief.

EXPERIMENTAL

Seeds of different species of lespedeza[4] were planted in stone jars containing Marshall silt loam which was well supplied with lime and phosphate. The following kinds of lespedeza used were:

	U.S.D.A. No.
Korean (*Lespedeza stipulaceae*)	22,457
Korean (*Lespedeza stipulaceae*)	19,604
Korean (*Lespedeza stipulaceae*)	19,601
Common lespedeza (*Lespedeza striata*)	22,590
Kobe (*Lespedeza striata*)	22,456

Three sets of pots were started in the greenhouse on April 27. One set was placed on carts so they could be rolled out of a ventilated dark room and exposed to 7 hours of daylight. A second series was placed under lights of approximately 250 foot candles so that the natural daylight could be increased to 17 hours. The third series was exposed to the normal period of daylight. The greenhouse equipment was the one described and used by Murneek (3) for photoperiodism studies.

[1]Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo. Journal Series No. 703. Also presented at the annual meeting of the Society held in Chicago, Ill., December 4 to 6, 1940. Received for publication December 13, 1940.

[2]Instructor in Soils.

[3]Figures in parenthesis refer to "Literature Cited", p. 236.

[4]Seed supplied through courtesy of Ronald McKee, U. S. Dept. of Agriculture.

Germination was completed on all varieties within 8 days. All made rapid growth, although the vegetation of the short-day series was darker green and gradually lagged in growth behind those receiving a longer period of illumination. After 49 days (June 15) the short-day plants were much smaller than the normal and long-day series. Observations were made every three or four days, and an examination made after 57 days (June 23) disclosed that all three *stipulaceae* varieties in the short-day series contained seeds which were difficult to observe. (See Fig. 1.) The early variety, No. 19,604, had the plumpest seed when first observed, indicating that they were formed first. Standard Korean, No. 22,457, had seeds that were not so far advanced, while seeds were just starting to form on the late variety, No. 19,601. The plants were about 7 weeks old and 2 to 3 inches tall. No visible flowers had appeared at any time on any of the *stipulaceae* varieties, and the seeds were borne in the axils of the leaves between the stipules. No visible vegetative branch was formed from the central stem, but rather the seeds appeared to be borne on the *stipulaceae* varieties in a manner similar to that which is normal for the *striata*, namely, in the axils of the leaves on the central stem. After 60 days (June 26) the seeds were forming on the Kobe variety, No. 22,456, and two days later distinct seeds could be noted on the Common lespedeza, No. 22,590. At no time could any visible flowers be observed on any of the varieties. After 73 days (July 9) all the plants in the short-day series, except the Common lespedeza, had started to mature and by 110 days (August 15) all except the Common lespedeza were dead. It was becoming very dry. None of the plants or varieties were over 3 inches high.

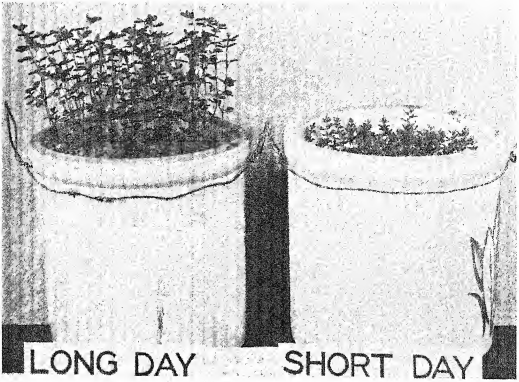

FIG. 1.—Standard Korean plants 60 days from planting. Left, 17-hour day; right, 7-hour day.

During this time the plants given the normal day and the long days had continued to grow and had shown no evidence of fruiting. By the middle of August (110 days) the long-day plants were about 16 inches high, while the natural day plants were about 12 inches. By 117 days (August 22) blooms were observed on the early variety, No. 19,604, of the natural day series. The complete set of days of blooming for the different varieties of the normal day series are given in Table 1.

TABLE 1.—*Dates of flowering of different lespedezas under normal length of day.*

Variety	Days from planting	Flowers first observed	Time between sunrise and sunset
L. stipulaceae, 19604.......	117	Aug. 22	13 hr., 26 min.
L. striata, 22590.......	121	Aug. 26	13 hr., 17 min.
L. stipulaceae, 22457.......	126	Sept. 1	13 hr., 02 min.
L. stipulaceae, 19601.......	126	Sept. 1	13 hr., 02 min.
L. striata, 22456.......	132	Sept. 7	12 hr., 46 min.

All the normal day plants continued to bloom for some time and produced seeds similar to those of plants in the field. During this time the long-day plants continued to make vegetative growth, but produced neither flowers nor fruits. After 187 days (October 31) when the day length was 10 hours and 34 minutes, and the long-day plants were over 24 inches high, the lights were removed and the exposure reduced to that of a normal day.

None of the long-day plants had formed blossoms by 217 days (December 1). At this season, when the day length was 9 hours and 39 minutes and the greenhouse was cooler, it was decided to use one-half of the pots of each variety and place at 80° F, while the remaining half was held at 60° F. Within five days after this change, blooms were noted at the higher temperature of 80° F on varieties Nos. 19,604, 22,456, and 19,601; and two days later the Kobe and Common varieties were blooming. At this time scattered blooms were also observed on all varieties at 60° F, and 33 days after the change all varieties both at 80° and 60° F had produced seeds, although those at the higher temperature were more mature. This behavior would indicate that the floral primordia were present and were dominant when this change was made. No doubt the higher temperature accelerated growth with the result that the plants at 80° F showed external evidence of blooming sooner than those at 60° F after the pots were divided.

DISCUSSION

The results obtained from these trials demonstrate that lespedeza is sensitive to the length of day. Supplementary illumination to give 14 hours of continuous light is now being successfully used if it is necessary to prevent fruiting when the plants are grown in the greenhouse during winter months.

Although this problem is directly concerned with the growth of lespedeza in the greenhouse, it is possible that the photoperiod effect

on lespedeza may be a factor in its performance in different sections of Missouri. The geographic limits of successful growth of Korean lespedeza has been set forth (7) as extending from the southern line of Tennessee and central Arkansas to the northern Missouri border and thence east across Illinois and Indiana. Both north and south of this area the amount of growth made by Korean is so small as to make it an inferior crop. It is not always possible in Missouri to correlate soil fertility with the ease of establishing a stand.

The dates of flowering of the normal-day plants (Table 1) would indicate that the processes which initiate flower primordia in lespedeza must become active during a time when the length of the sunlight period is sufficient to permit development of the flower buds so they will open when the day length is between 13 and 14 hours. The first flowers observed in this experiment were on the variety No. 19,604, an early selection of Korean, and appeared on August 22 when the time between sunrise and sunset was 13 hours and 26 minutes. The latest variety to flower was the Kobe, where the first flowers appeared on September 7 when the period between sunrise and sunset was 12 hours and 46 minutes. This would indicate that the earlier varieties will start fruiting with a longer day, while the Kobe variety, which is adapted to the South and to a short summer day, does not flower until late in the season. This would suggest that when southern grown seed is used in the northern part of Missouri, the reproductive processes will be delayed until the length of the daylight period is short. Frost may then kill the seed before maturity.

If a daylight period of from 13 to 13½ is necessary to initiate reproduction in lespedeza, which would not occur before September 1 in northern Missouri and three or four days earlier in southern Missouri, then an additional six weeks growth would probably be required to mature seed sufficiently to escape injury by frost. (See Fig. 2.) If October 16 is taken as the date when lespedeza seed would be mature in north Missouri, there have been 7 years in the last 20 when frosts occurred before this date, while if October 30 is taken as the maturity date in south Missouri then killing frosts have occurred earlier in only 1 year in the last 20. This might partly explain the greater success of the lespedeza in the southern part of the state than in the northern part.

It is also possible that the short period of daylight during the spring in northern Missouri may have some effect on the vegetative growth of lespedeza. Lespedeza germinates during warm periods in northern Missouri in the spring almost as early as it does in the southern part of the state. However, it frequently makes very slow growth and has a pale color. No doubt this is partly due to low temperatures. However, even after the weather becomes warm it makes neither as rapid nor as consistent a growth at this time of the year as it does in the southern part of the state. It seems possible that in the spring, while the seeds are germinating and the period of daylight is shorter than 13 hours, the reproductive process might be initiated in these small plants. This tendency toward reproduction would serve to militate against fuller vegetative functions. This disturbance may not be sufficient to cause fruiting and it may be prevented later by the light

period gradually becoming longer. However, even after the weather becomes warm and conditions are favorable for growth, the inhibiting changes that may have taken place might be sufficient to retard vegetative growth and prevent normal development. Such a condition has been found by Murneek (4) with Biloxi soybeans. When plants were grown for two weeks under a short day and then switched to a long day, they did not make as satisfactory growth as the plants which were continually subjected to a long day.

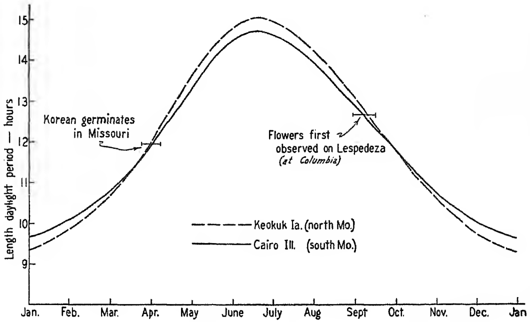

FIG. 2.—Length of daylight period in north and south Missouri.

This condition, however, would probably not be greatly significant within Missouri since there is little difference in the length of day from north to south at this time, and the plants grown in the southern part of the state would also be subjected to a slightly shorter day. It is probable that temperature alone or a combination of both temperature and length of day would more likely be responsible for this condition.

A modification of this same condition might also explain the poorer growth of lespedeza in the Gulf states than is secured in the central states. It is possible that with the shorter days, only slightly over 14 hours on June 21 at New Orleans (1), the reproductive process might be initiated before a satisfactory vegetative growth is made. This would be in agreement with the smaller foliage yields but satisfactory seed production which is obtained in these states.

To substantiate further this theory of the effect of length of day on the fruiting of lespedezas, a consideration of their origin is significant. The Common *striata* variety distributed throughout the South has been known since the Civil War (7). Kobe was found near Kobe, Japan, which has a latitude of about 35° North. This corresponds with the southern line of Tennessee which is not far from the center of the most satisfactory growth of this variety in this country.

Korean was found at Sorai Beach near Seoul, Korea. This is at a latitude of about 37½° North, which corresponds to southern Missouri and, according to Pieters (7), is about the center of the area of adaptability for Korean in this country. Harbin was found at Harbin, Manchuria, which has a latitude of about 45° North and corresponds to central Minnesota. It has been grown successfully in this region. With such a close correlation between regions of origin in Asia and the areas of adaptability in this country, it seems that day length is an important factor in growth and seed production of lespedeza.

CONCLUSIONS

When lespedeza seedings are grown in the greenhouse during winter when the days are short, artificial illumination must be supplied to prevent the plants from seeding and discontinuing their growth. The length of day must be more than 14 hours to prevent this fruiting. It seems logical that this photoperiod response of Korean might be responsible for the better results obtained from it in the region of Kentucky, Tennessee, southern Missouri, and northern Arkansas than in northern Missouri or in the states farther south. It is possible that in northern Missouri the reproductive process is not initiated soon enough to permit the seed to mature before frost; or that during the short days of spring the changes in the plant which cause fruiting, coupled with low temperatures, may be started sufficiently so as to retard the vegetative growth when the days become longer and the temperature is favorable for growth. This would seem particularly significant when much of the seed used in northern Missouri the past few years has come from the South. It is possible that this seed has not been adapted to the temperatures and day lengths in northern Missouri and has been responsible for the poorer showing of Korean in that part of the state.

It is probable that with the continuous use of locally grown seed in northern Missouri, poorly adapted plants and seed will be eliminated and in time the crop will give more satisfactory results. It is probable that through selection and breeding some strains of lespedeza can be developed which will fruit under different lengths of day and thus push the limits of its adaptability and use farther north and farther south from the regions where it can be satisfactorily grown at the present time.

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INTEGRATING SOIL AND CROP RESEARCH[1]

Robt. M. Salter[2]

TO integrate means to complete by the addition of parts, or to combine individual parts into a whole. If I interpret correctly this subject, "Integrating Soil and Crop Research", my job is to show a need or an opportunity for the correlated acquisition of both soil and crop information in the study of soil and crop problems. Some may ask, "Is not the acquisition of both soil and crop information common procedure in soil and crop research today?" My answer is that in the study of problems involving soil and crop interrelationships we too commonly content ourselves, sometimes justifiably, with only gross or superficial characterization of soil conditions or crop response. We do something to the soil, grow a crop, and measure the yield. Sometimes we do a little more than this, we may make a measurement or two to give a little insight into what our treatment has done to the soil, or we may make certain observations regarding the crop's response other than yield, such as time to maturity or composition of the crop. Often the results obtained give a sufficiently adequate answer as to what to expect under the existing conditions to permit practical recommendations. In fact, most of our advances in soil and crop management have been based on precisely this type of information. Unfortunately, it is seldom that such experiments yield a clear-cut answer as to *why* a given response is obtained. Perhaps that should not worry us so long as we feel reasonably certain that it will be obtained with sufficient regularity to justify practical recommendations.

But we do worry about not knowing more about the "why" of our results, and for two reasons. In the first place, we like to think of ourselves as scientists and we are aware that learning why things happen is the very essence of scientific inquiry. In the second place, most of the responses we get do fluctuate notably as we repeat our experiments in different seasons or on different soils, and even though we repeat them sufficiently to warrant legitimate generalizations, there are usually doubts as to their application to conditions not actually encompassed by the studies made. Then too, not infrequently the results in different seasons or on different soils fluctuate so violently as to render generalizations dangerous or impossible. Every agronomist has a graveyard where he files the results of such experiments.

Concurrently with the development of the other natural sciences, but with some inevitable hysteresis, there have developed creditable bodies of scientific information about soils and plants. Already soil science has grown to the stage where it has seemed desirable to break it down into a number of divisions. Thus we have soil physics, soil chemistry, soil physical chemistry, soil microbiology, soil genesis and morphology, etc. Similarly plant science has been divided into its

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parts, plant physiology, plant chemistry, plant morphology, anatomy, histology, cytology, genetics, etc.

To a notable degree, soil science and plant science have developed independently. Among workers in both fields it is even possible to find some individuals who are prideful in their disregard of the indisputable facts that man is primarily interested in the soil as a medium for growing plants, and reciprocally, that in nature the development of the plant is inescapably dependent upon the qualities of the soil that supports it. In fact, a large proportion of the almost innumberable problems of plant growth of concern to agriculture and forestry involve soil-plant interactions. Only through critical study of the interactions of soil properties and processes with plant properties and processes may we hope to discover scientific explanations for the effects of soil on plant or of plant on soil. Only by such studies may we hope to raise the production phases of agronomy, horticulture, and forestry to the level of sciences. It would be inept to imply that information in this realm of soil-plant interactions is wholly lacking. Actually we are accumulating a considerable body of such information. However, much of it is still unrelated and fragmentary. To be convinced of the paucity of information in this field one needs only to scan any modern treatise on soil physics, soil chemistry, or soil micro-biology with this question in mind, "What is the precise significance to plants of the soil characteristics and processes discussed?" One can scarcely help being impressed with the size of the void thus disclosed. It is true that we are continually making use of the facts of soil science and of plant science in building hypotheses to explain results obtained in empirical experiments. It is equally true that we find few projects in which the essential research to prove such hypotheses is a part of the project itself. One thesis of this discussion, therefore, is that in experiments which aim to measure the response of crops to given soil conditions or treatments, or the effects of certain crops upon the soil, we not content ourselves with gross measurements, but instead so far as feasible, include in our research interpretive studies of both soil and plant designed to evaluate the important soil-plant interactions and yield a reasonably valid scientific explanation of the results. This proposal is made with full realization of the difficulties and limitations involved and the knowledge that pressure for practical answers will continue to necessitate a goodly proportion of empirical experimentation.

Before proceeding further with this idea, we shall digress temporarily to discuss two concepts that bear upon it. Neither is new but neither has been given the recognition it deserves in soil-plant research. The first is that in soil-plant problems we are dealing with dynamic, not static, systems of interacting properties and processes. Each of the many soil properties that influence crop growth undergoes continual change during the life of the plant, changes reflecting the influence of climatic factors, biological activity within the soil, changes brought about by the plant itself, changes resulting from treatments given by man. The growth of the plant is equally dynamic, involving continuous changes in properties and processes reflecting fluctuations in both soil and atmospheric environments, progression

in its physiological growth cycle, treatments given the plant by man or animals, etc. The final yield of any crop represents the integrated effect of a whole series of interacting and fluctuation influences and processes. It is easily possible that identical yields of a given crop may result from widely divergent sequences of developmental processes. For example, several years ago, in attempting to reduce the heavy infestation of corn by the European corn borer normally associated with rapid early development on fertile soils, the writer succeeded fairly well by the simple expedient of first retarding early growth by incorporating in the soil a large amount of carbonaceous material, resulting in microbiological competition for nutrients, followed by generous side-dressing with fertilizer to hasten growth after the egg-laying period was passed. The final yield was little affected, although arrived at by quite different sequences of growth processes as shown by periodic measurements of height and of plant composition. Considering the continually varying intensity and quality of the factors involved in problems of crop growth it is obviously illogical to expect that single isolated measurements will adequately characterize conditions within either the soil or the plant. Perhaps we need to develop more of a "motion picture" approach in our study of these conditions. Only in this way may we hope to reach an intelligent understanding of them.

A second concept that merits wider appreciation in studies dealing with soil-plant interactions relates to the dimensional aspects of our approach. To a growing plant the soil is anything but a homogenous medium. Instead it is extremely heterogenous. The pattern of root development within a given soil, regardless of how haphazard it may appear, reflects the net effect of varying complimentary or opposing stimulae to which the growing roots are subjected, such as gradients in nutrient concentration, in moisture or oxygen tensions, etc. Moreover, at any one time only a small portion of the soil is actually contributing to the nutrient or moisture supply of the plant, being that part directly in contact with the functioning root hairs, the latter representing only a small and continually changing part of the total root system. With these facts in mind, it is clear that gross measurements on soil composition, moisture content, etc., the kind usually made, may be quite unreliable criteria of the soil conditions actually affecting the growth of a plant. Obviously there is need for a more refined approach in studying soil-plant problems. Unfortunately, the techniques for such an approach remain for the most part to be developed. It may not be unreasonable to hope, however, that through the application of the procedures of micro-chemistry, spectroscopic analysis, and the like, eventually it may be possible to gain a clearer picture of conditions at or near the zone of actual root-soil contact. Even without such procedures, there would appear to be considerable opportunity to refine out methods of soil examination by sampling in a manner to more closely represent those zones actually occupied by growing roots.

Reverting now to the idea that intensive studies of soil-plant interactions are essential to a scientific understanding of many problems in what we choose to call the applied fields of agronomy, horticulture,

and forestry, let us consider the type of research organization necessary for such an approach. Obviously, we cannot expect the general agronomist, horticulturist, or forester to do the job unaided for the patent reason that he lacks sufficient training in the specialized divisions of soil and plant science. The alternative would appear to be a grouping together of specialists in the various fields organized for collective attack on these problems. Many of our land grant colleges already have in their employ specialists in each of the essential divisions of soil and plant science. The same is true of the federal Bureau of Plant Industry. The fact that more research of the type we have been discussing is not underway probably reflects in part failure to appreciate the opportunities and need for such work, and in part a mistaken philosophy that problems in the applied fields do not afford opportunity for work equal in scientific dignity to those in the more abstract branches of soil and crop science. Fortunately, we do find an increasing number of instances of soil and crop scientists working together an applied problems. One example comes to my mind in which the practical problem of orchard irrigation in the humid region is being attacked jointly by a well-trained soil physicist and an equally well-trained plant physiologist. In addition to the usual control of water additions and measurements of yield, the procedure in this study involves detailed and continuous measurement of moisture distribution throughout the root zone, evaluation of the moisture supplying properties of the soil in terms of pF measurements, continuous growth records upon the twigs, leaves and fruits, measurements of diffusion pressure, transpiration rates, stomatal behavior, etc. It can scarcely be doubted that the principles likely to be established in work of this kind should afford a sounder guide to irrigation practice than any amount of empirical experimentation.

The advantages of organizing for collective action in soils and crops research are well stated by Sir John Russell in the last edition of his well-known book, "Soil Conditions and Plant Growth", as follows:

"In modern experimental stations, the tendency is towards team work. As an instance chosen because it is best known to the writer: At the Rothamsted Experimental Station, instead of a number of isolated individuals, there is a body of workers investigating the subject, each from his own special point of view, but each fully cognisant of the work of the others, and periodically submitting his results to discussion by them. Separate workers investigate respectively the bacteria, protozoa, fungi, algae, helminths, and insects of the soil; in addition physical and organic chemists are studying the soil conditions, while others are concerned in the study of the growing plant. A body of workers by harmonious cooperation is able to make advances that would be impossible for a single individual, however brilliant."

In this country we find a growing tendency to adopt this type of organization, as evidenced by the staffing of some of the new regional Bankhead-Jones laboratories. The organization of the new Regional Salinity Laboratory at Riverside, California, is an outstanding example of the bringing together of a group of scientists, each highly trained in a particular branch of soil or crop science, to work col-

lectively upon problems within a given field of applied soil and crop research.

Perhaps it may add specificity to this discussion to suggest in some detail how some particular soil-plant problem might benefit through cooperative attack by a group of workers in the different branches of soil and plant science. Since the number of problems that would so benefit is almost legion, it should not be inferred that there is anything unique about the particular example chosen.

For several years the writer has been interested in the problem of fertilizer placement. As you know, this problem has been the subject of a large program of research, cooperative among many states, the U. S. Dept. of Agriculture, and certain commercial agencies. For the most part this research has been of an empirical nature. With different crops on different soils the fertilizer has been placed in different positions with respect to the seed and the effects on germination and yield measured. It was early discovered that the results varied from season to season, so that some cognizance has been given to weather. In some cases the rate at which the crop grew was determined, and in a few experiments some study was made of root distribution in relation to the location of the fertilizer. The chief result of all this work has been to show that in spite of seasonal variations to the contrary, placing the fertilizer in bands at the side of the seed gives generally reasonably high efficiency associated with little deleterious effect on germination or growth of the young plant. This result has eminently justified the program and already has led to notable advance in practice.

But, it would be foolish to conclude that the problem of fertilizer placement is solved and nothing further needs to be done about it. There have been too many instances in which other methods were superior to side application. Even with side application, studies of depth of incorporation have led to few important generalizations, the results being more greatly influenced by weather conditions and the nature of the soil. Moreover, most of the studies have been made with mixed fertilizers and only recently has it been recognized that the most efficient spatial distribution of nutrients in the soil may require different placements with each of the fertilizer nutrients or that different carriers of a single element may call for different methods of placement.

Another disturbing feature of this placement work has been the fact that under many situations the maximum amount of fertilizer that can be applied economically in the row supplies only a small part of the quantity of certain nutrients known to be required for high yields, yet attempts to supplement row applications by broadcast additions have generally given disappointing results. Recent studies in which fertilizers have been plowed down prior to planting corn and other crops represent an attempt to increase the effectiveness of such supplemental treatments. The fact is that if we appraise honestly our knowledge of fertilizer placement we are forced to conclude that we know very little about the fundamental principles involved.

The problem is indeed a complicated one, involving interactions of soil and plant which are hopeless of solution without focusing upon

them the combined talents of a considerable array of soil and crop scientists. What is the nature of the physico-chemical reactions taking place between the various fertilizer salts or mixtures and the soil? How are these affected by the properties of the soil, moisture levels, method of placement, etc? For any given treatment, how do the nutrient ions distribute themselves within the soil profile and how is the pattern influenced by the movement of water? What is the picture as regards osmotic concentration of the soil solution? Under what conditions and to what degree do microorganisms compete with the crop for the nutrients added? How is root development influenced by the various conditions of nutrient and osmotic concentration? What conditions of osmotic concentration interfere with germination of the seed or result in damage to roots or plumules? For any given nutrient ion, what concentrations and what distribution pattern is most favorable to growth? At what rates are the nutrient ions absorbed by the plant under various conditions? In what ways are the growth processes of the plant affected physiologically, morphologically, chemically? Certainly this one problem, and it is not exceptional, includes plenty of fundamental questions to challenge the best efforts of a considerable group of soil and crop scientists. And, just as certainly, without the collective effort of such a group, we are unlikely to proceed beyond the "rule of thumb" stage in fertilizer placement practice.

We may consider this problem of fertilizer placement merely a typical example of almost innumerable problems in soil and crop research. In this case chief interest lies in the effects that certain soil conditions have upon the crop. There are many problems in which our main interest lies in the opposite direction, namely, in the effect of the crop on the soil. This is particularly true in studies aimed at determining the effect of individual crops or of crop rotations upon the productivity of the soil or upon soil erosion or water conservation. Here again we possess considerable empirical information but understand few of the fundamental principles involved. For example, we recognize differences among crops in their effects on soil structure, but we possess little or no scientific understandings of the mechanisms involved. The same is true of our knowledge of the effects that different crops have upon those physico-chemical properties of the soil concerned with mineral plant nutrition. Not infrequently we find ourselves in the dilemma of being unable to make practical applications of our empirical findings because of contradictory evidence. In Ohio, for instance, soybeans tend to improve the yields of subsequent crops on Brookston clay and to depress them on Wooster silt loam. What to expect on other soils is anybody's guess.

One important division of crop science that would appear to offer considerable opportunity for closer integration both with other fields of crop science and with soil science is that of crop breeding. With many of the major crops improvement through breeding has progressed to the stage that little further progress is likely from efforts centered only on yield or on readily observable morphological characters. More and more breeding effort is being directed toward the development of strains that are resistant to drouth, to cold, to heat, or to attack by

specific diseases or insect pests, strains that have superior qualities as food for animals or man, strains that are better adapted to certain soils or that are more tolerant of unfavorable soil conditions. To a large extent the hereditary factors involved in such breeding efforts are physiological in character. I believe it a safe statement, however, that to date and with a few exceptions, plant physiologists have played too small a part in this research. To a still less degree have soil scientists been brought into the picture, although modification of the pattern of soil-plant interactions obviously is involved in such matters as drouth resistance, resistance to injury by heaving, and adaptation to given levels of nutrient supply. Here again, attainment of practical objectives would seem to be dependent upon better integration of effort. Consider the fact, for example, that it has been known for several years that different inbred lines of corn grown on the same soil take up varying amounts of the individual mineral nutrients and that these differences appear to be hereditary. It would appear that such knowledge might be put to important practical use in the development of hybrid strains adapted to growing on soils having high or low nutrient levels, strains supplying more of certain mineral elements needed by animals, or strains that might serve as purveyors of nutrients to other crops in the rotation in systems involving the return of residues or manure. Actually, before intelligent progress can be made toward any of these objectives, an understanding of the physiological significance of these variations in mineral uptake is necessary. For example, if a strain is a "high potassium accumulator", does it mean that it possesses a higher capacity to extract potassium from soil minerals, and for that reason might be expected to do well on potassium impoverished soils? Or, does it mean that the strain actually requires more potassium for growth and hence might be expected to do well only in the presence of abundant supplies of available soil potassium? Are these differences related to the extent of root-soil contact and how are they affected by varying soil conditions? Obviously we cannot expect the corn breeder to answer these questions.

As a final illustration of the need for more integration in soils and crop research, it is suggested that the value to agriculture of the important division of soil science known as genesis and morphology might be enhanced by its somewhat closer integration with crop science and with those phases of soil science underlying soil management. Our modern science of soil genesis and morphology, upon which is based the classification of field soils, has been developed with the concept of the soil as a natural system whose present physical, chemical and biological characteristics represent merely the current status in a long time series of evolutionary changes from the parent material to a condition known as maturiety. The entire process has been related to such factors as climate, nature of parent material, topography and natural vegetation. Classification is based upon such inherent characteristics of the undisturbed natural soil as morphology, texture, structure, color, etc., whose relation to the genetic process has been the subject of much productive research. All this is probably as it should be. Certain difficulties attend the practical use of the concepts

generated. One of these is that in putting the land to crop, man rudely interrupts nature's process and injects a whole series of rapid changes which may obliterate or change materially many of the landmarks used in characterizing the natural soil. Another difficulty lies in the fact that the many characteristics employed in classifying soils have not been evaluated adequately as regards their direct effects on plant growth or their meaning in terms of soil management.

It is true that for the most part agronomists and others engaged in field experimentation or responsible for practical recommendations have shown remarkable faith in the soil classifiers, for, by and large, the assumption is made that the soil type is the proper unit upon which to base practical recommendations and research. For the most part this is probably a safe assumption. On the other hand, the observation of Lyon[3] in 1932 that variations in fertilizer response within a single type sometimes may be as large as between types seems to have been overlooked. In recent years complications have arisen because soil surveyors, in their zeal for precise discrimination, have found justification for splitting up a good many of the older soil types into several new ones, besides discovering a lot of new ones that they had previously overlooked. It is probably not an over-statement to say that some agronomists are becoming a bit confused.

All of which leads me to believe that we may need to evaluate more definitely the meaning of soil classification variables in terms of their effects on growing plants and on response to soil management practices. It would seem that this is a problem of sufficient importance to warrant direct experimental attack. There are several possible angles of approach. One type of experiment that might be useful would be to grow pure strains of some of the more important crops at each of several locations upon each of several soil types in a state or region under as nearly uniform culture as possible, with measurements designed to give a progressive picture of growth in size, of rate of physiological development, information on extent and pattern of root development in relation to soil characteristics, chemical composition of the plant at different stages, etc. Repetition to allow for differences in seasonal conditions probably would be necessary. Similar experiments might be planned to measure the influence of soil characteristics upon the various practices of soil management. Their significance in relation to erosion control procedures would be especially valuable.

Before concluding, I would like to say a word in favor of another type of integration in soils and crops research. I am not sure but that what I have in mind is better designated as coordination than as integration. I refer to the desirability of a regional or national approach to certain soil problems, more particularly those in which response is influenced both by climatic and soil factors. It seems somewhat of a paradox that there should have been more regional coordination of effort in certain phases of crop research, especially in crop breeding, than in soil research with the notable exception of the soil survey even though a soil's reponses are more intimately bound to its par-

[3]Lyon, T. L. Is the soil type homogeneous with respect to its fertilizer needs? Jour. Amer. Soc. Agron., 24:58–71. 1932.

ticular locale than are those of a crop, which means that generalizations in field soil studies are only possible through coordinated experimentation in separate areas. Among the various phases of soil science there would appear to be many opportunities to develop coordinated regional studies that might be expected to yield enlightening generalizations. For example, it would be valuable both scientifically and practically to evaluate the influence of certain crops or of certain cultural practices on soil organic matter and nitrogen under a wide range of conditions as regards soil characteristics and climate. Similarly, coordinated studies of the comparative efficiency of different forms of nitrogen fertilizers might serve to establish useful principles. Coordinated studies dealing with the need for the so-called minor elements might reveal interesting relations to soil origin and climate. These examples could be multiplied greatly.

There are probably several reasons for the failure to develop more of the regional approach in soil research. An important one has been the mere physical and financial impediments to research workers of several states getting together to plan for collective effort. Another has been the separation until recently of soils and crops research in the U. S. Dept. of Agriculture and the failure in certain areas of soil research to recognize that one of the most effective contributions a federal bureau can make to progress in agricultural research is in supplying leadership and otherwise implementing regional programs of research cooperative with the states. Fortunately, these latter impediments no longer exist.

Finally, it must be admitted that failure both to integrate and to coordinate in all fields of agricultural research finds a partial explanation in the fact that some research workers and even some research administrators have not learned the true meaning of cooperation. Cooperation which begins after a project is planned or ends before the results are interpreted will contribute little toward the objectives we have been discussing. Lack of understanding either of the meaning of cooperation or of its merit in research is perhaps not surprising in those who obtained their early training in the era when research was largely on an individualistic basis. That this era is rapidly giving way to one of collective effort is increasingly evident. In recognition of this transition, and as a means of expediting it, I shall conclude with the suggestion that in training the men who will do the research work of tomorrow, formal instruction dealing with the philosophy, the advantages, and the methodology of cooperation in research might be a useful addition to our curricula of graduate instruction.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, X[1]

T. R. STANTON[2]

THE ninth consecutive report (3)[3] on the registration of improved varieties of oats was published in January 1940. During 1940, six varieties, listed and described below, were approved for registration:

Group and varietal name	Registration No.
Early red:	
Fultex	92
Early yellow:	
Vicland	93
Midseason red:	
Ranger	94
Rustler	95
Midseason yellowish-white to white:	
Huron	96
Uton	97

FULTEX, REG. NO. 92

Fultex (C. I. 3531)[4] was selected from a cross (No. X3020) between Fulghum (C.I. 708) and Victoria made at Arlington, Va., in 1930 by F. A. Coffman. Bulk seed for the F_3 generation was sent to Texas Substation No. 6, Denton, Tex., in 1932. Fultex (Tex. No. 12–34–33) was selected in 1933 by I. M. Atkins. It was subsequently tested and increased by I. M. Atkins and P. B. Dunkle, and distributed to farmers of north central Texas in 1940. Fultex was bred cooperatively by the Texas Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

Fultex is classified as an early to midseason short, stiff-strawed variety belonging to the red oat group (*Avena byzantina* C. Koch). However, in some characters, it is more or less intermediate between red and common oats (*A. sativa L.*).

In a statement by I. M. Atkins, submitted with the application for registration, Fultex is described as having shorter and stronger straw than Fulghum and as being outstanding among all commercial red oat varieties in its ability to stand long after maturity for combine harvesting. It is about 5 days later than Fulghum and 4 days earlier than Red Rustproof at Denton. It is resistant to smut and crown rust. The grain is very high in test weight, being short and plump with a short black (on the lower portion) awn, which threshes off easily.

[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication, December 19, 1940.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, member of the 1940 Committee on Varietal Standardization and Registration, charged with the registration of oat varieties.

[3]Reference by number is to "Literature Cited", p. 251.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

Fultex is less productive than the New Nortex (Red Rustproof type) oats under favorable conditions, but more productive under adverse conditions incident to disease or storms.

Fultex has been tested in replicated nursery plots from fall seeding since 1937 and from spring seeding since 1936. It also has been tested in replicated field plots from both fall and spring seeding since 1938. The yields of Fultex and three standard varieties are shown in Table 1.

TABLE 1.—*Yields of Fultex and of three standard varieties of oats at Denton, Tex.*

Variety	C. I. No.	Acre yields, bushels					
		1936	1937	1938	1939	1940	Av.
Fall-sown Nursery Plots							
Fultex	3531	—	79.2	95.6	82.4	91.2	87.1
Frazier	2381	—	78.6	95.9	67.2	83.2	81.2
Fulghum	708	—	79.2	87.8	65.6	82.2	78.7
New Nortex	3422	—	99.1	92.9	86.2	94.0	93.1
Fall-sown Field Plots							
Fultex	3531	—	—	92.2	67.0	70.0	76.4
Frazier	2381	—	—	78.5	61.2	63.8	67.8
New Nortex	3422	—	—	92.9	77.8	77.8	82.8
Spring-sown Nursery Plots							
Fultex	3531	68.0	55.6	92.9	78.6	78.6	74.7
Frazier	2381	74.5	66.9	72.6	—	70.4	71.1
Fulghum	708	40.0	67.2	77.6	—	73.2	64.5
New Nortex	3422	73.6	79.6	57.5	—	80.5	72.8
Spring-sown Field Plots							
Fultex	3531	—	—	63.4	59.9	73.6	65.6
Frazier	2381	—	—	48.7	67.3	64.9	60.3
New Nortex	3422	—	—	47.4	54.9	79.6	60.6

For further information on yields, etc., of Fultex, see mimeographed publications.[5]

VICLAND, REG. NO. 93

Vicland (C.I. 3611) (Selection No. 5545-16) was originated from a cross (No. XS1098) between Victoria and Richland, made by T. R. Stanton at Arlington, Va., in 1930 (4, 5). It is 1 of 33 strains from the Victoria × Richland cross, sent to the Wisconsin Agricultural Experiment Station, Madison, in 1935, that had been selected at the Aberdeen Substation, Aberdeen, Idaho, in 1934. Other selections of this cross from Aberdeen, Idaho, sent to Ames, Iowa, in 1935, gave rise to the varieties Boone (C.I. 3305) (3) and Control (C.I.3603).

[5]ATKINS, I. M., and DUNKLE, P. B. Report of oat variety tests. Tex. Agr. Exp. Sta. 672 Progress Rpt. April 19, 1940. [Mimeographed.]
COFFMAN, F. A. Results from the cooperative coordinated oat breeding nurseries for 1939, and the uniform winterhardiness nurseries for 1939-40. U. S. Dept. Agr., Bur. Plant Indus., Div. Cereal Crops and Diseases. Sept. 15, 1940. [Mimeographed.]

Selection No. 5545-16 was named Vicland in 1940 (6) by H. L. Shands and B. D. Leith, who also submitted the application for its registration.

Vicland thus was developed cooperatively by the Wisconsin, Idaho, and Iowa Agricultural Experiment Stations and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Those having a part in the breeding of Vicland are H. L. Shands, B. D. Leith, T. R. Stanton, H. C. Murphy, F. A. Coffman, Harland Stevens, H. B. Humphrey, and L. C. Burnett. According to H. L. Shands and B. D. Leith, Vicland is high in yield and resistant to the now prevalent races of rusts and smuts occurring in the North Central States. It is not recommended for poor sandy soils.

Vicland is early, with short, fine straw of medium strength. The leaves fleck when attacked by crown rust, and, although telia sometimes form, Vicland is susceptible only to races of stem rust that now occur late in the season. Vicland is resistant to the smuts, although it may not be immune. The hulls are yellow and the kernels usually are well filled with a high test weight.

Vicland is being distributed for commercial production in 1941, in lots of 10 to 60 bushels, to certified seed growers who are members of the Wisconsin Agricultural Experiment Association.

Vicland was tested in nursery or field plots in Wisconsin for 6 years at Madison, 4 years at Marshfield, 4 years at Ashland, and 3 years at Hancock. It has been grown in replicated nursery plots and in 1/60-acre plots at Madison in comparison with standard varieties. The yields of Vicland and State Pride in the nursery at Madison are given in Table 2.

TABLE 2.—*Yields of Vicland and State Pride oats at Madison, Wis.**

Varieties	C. I. No.	Acre yield, bushels					
		1936	1937	1938†	1939	1940	Average
Vicland	3611	45.3	65.0	95.4	69.4	76.1	70.2
State Pride	1154	40.9	57.9	34.1	63.7	70.4	53.4

*Data on yields of Vicland and other varieties and strains of oats also have been recorded by Coffman. (See footnote 5.)

†An extremely severe epidemic of crown rust occurred in 1938.

RANGER, REG. NO. 94, AND RUSTLER, REG. NO. 95

Ranger (C.I. 3417) and Rustler (C.I. 3754) were selected from a cross (No. X3012) between Nortex (Red Rustproof type) and Victoria oats made by F. A. Coffman at Arlington Farm, Va., in 1930. The early hybrid generations were grown at Aberdeen, Idaho, or in the greenhouse at Arlington Farm, and bulk seed from F_4 plants was sent to College Station, Tex., in the fall of 1933. Plants resistant to crown rust and having a winter growth habit were selected by P. C. Mangelsdorf in 1934. Testing of the selections, continued by P. C. Mangelsdorf, I. M. Atkins, and E. S. McFadden, at College Station and Denton, Tex., permitted an elimination of susceptible progenies. The outstanding productiveness of both Tex. M19-17 and Tex.

M19–19 was apparent by 1936, and they were named Ranger and Rustler, respectively, in 1940. Thus these varieties were developed cooperatively by the Texas Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

Both Ranger and Rustler are early to midseason varieties of the Red Rustproof type (*Avena byzantina*). They are similar to the Nortex parent, except in being earlier and shorter. Rustler is about a week earlier than Nortex. The superior characters of these new red oat varieties are earliness, high yield, and resistance to the races of crown rust and smut that occur in Texas.

Ranger and Rustler appear to be adapted to different sections of Texas. They are being increased for possible distribution in the fall of 1941.

Ranger and Rustler and other selections were tested for 5 years in replicated nursery plots in comparison with Nortex and other standard varieties at College Station, Tex., and at other stations in the state, for 3 years. The yields at College Station are shown in Table 3.

TABLE 3.—*Yields of Ranger, Rustler, and Nortex oats at College Station, Texas.*

Variety	C. I. No.	Acre yield, bushels					
		1936	1937	1938	1939	1940	Average
Ranger	3417	69.2	41.5	56.9	28.8	46.1	48.5
Rustler	3754	66.7	24.7	46.2	28.2	36.3	40.4
Nortex	2382	47.2	33.6	40.8	29.3	34.1	37.0

HURON, REG. NO. 96

The origin of Huron (C.I. 3656) is as follows:

A cross between the Markton and Victory varieties was made by G. A. Wiebe at Aberdeen, Idaho, in 1923, and selections from this cross were sent to the Farm Crops Section of the Michigan Agricultural Experiment Station by T. R. Stanton in 1929 (1).

Plant selections were made in 1932 to purify one of the strains then designated as C.I. 2590. One of these reselections, No. 5210, appeared promising enough to warrant testing in several parts of Michigan. It was increased in 1938 and 1939, and then named Huron.

A sib of the original selection (C.I. 2590) was tested and distributed in Idaho under the name Bannock (2). Those who had a part in the development of Huron are E. E. Down, J. W. Thayer, T. R. Stanton, G. A. Wiebe, F. A. Coffman, L. L. Davis, A. E. McClymonds, and V. F. Tapke. The application for the registration of Huron was submitted by E. E. Down of the Michigan Station.

Huron is an early to midseason, yellowish-white to white oat similar to Silvermine. The superior characters of Huron are a long fruiting period, high yield, earlier maturity than Wolverine, high resistance to smut, and high test weight. It has been tested in nursery plots in six replicates at East Lansing for 5 years. The yields and test weights of Huron in comparison with Wolverine, a leading standard variety in

Michigan, are shown in Table 4. Huron is recommended for soils in the lower peninsula where the Wolverine variety is adapted.

TABLE 4.—*Yields and test weights of Huron and Wolverine oat varieties grown in replicated plots at East Lansing, Mich.**

Variety	C. I. No.	1936	1937	1938	1939	1940	Average
			Acre yield, bushels				
Huron	3656	78.9	63.2	84.8	91.7	82.0	80.1
Wolverine	1591	76.0	56.8	78.8	84.4	81.5	75.5
			Test weight, pounds				
Huron	3656	37.8	31.2	34.7	38.0	38.4	36.0
Wolverine	1591	34.8	24.6	29.8	33.5	38.1	32.2

*Yield data on Huron and other Michigan varieties also have been recorded by Coffman. (See footnote 5.)

UTON, REG. NO. 97

Uton (C.I. 3141) (Utah Sel. 153–5–10) was originated from a cross between Markton and Swedish Select oats made at Aberdeen, Idaho, in 1923, by G. A. Wiebe. In 1929, a group of selections from this cross was sent from Aberdeen to the Utah Agricultural Experiment Station at Logan. In that year, reselections were made by D. C. Tingey.

Uton was developed cooperatively by the Utah, Idaho, and Montana Agricultural Experiment Stations, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Those having a part in the breeding of Uton oats were D. C. Tingey, R. W. Woodward, G. A. Wiebe, T. R. Stanton, F. A. Coffman, and A. G. Goth. The application for registration of Uton was submitted by D. C. Tingey and R. W. Woodward, who named and first distributed the variety in 1937.

Uton is a rather tall, midseason, yellowish white variety of common oats, somewhat intermediate in grain characters between Markton and Swedish Select.

The superior characters of Uton are high yield and high resistance to the races of oat smuts prevalent in Utah and adjacent States.

Uton was tested at Logan, Utah, in replicated nurseries for 10 years and in field plots for 5 years. Furthermore, it has been tested in nurseries in other sections of the state for 1 to 7 years. Yield and smut infection data are shown in Tables 5, 6, and 7.

TABLE 5.—*Yields of Uton, Swedish Select, and Markton oats at North Logan, Utah.*

Variety	C. I. No.	Acre yield, bushels					
		1936	1937	1938	1939	1940	Average
Uton	3141	109.6	109.2	131.8	138.8	118.8	121.6
Swedish Select	134	129.1	116.0	137.1	146.4	125.3	130.8
Markton	2053	111.0	102.7	125.7	148.6	119.8	121.6

TABLE 6.—*Average yields of the Uton, Swedish Select, and Markton varieties grown in replicated nursery rows in seven Utah counties for 1 to 10 years.**

Variety	C.I. No.	County, years grown, and average acre yield, bushels							
		Cache, 10 years	Salt Lake, 7 years	Box Elder, 2 years	Sevier, 4 years	Utah, 2 years	Iron, 5 years	Uintah, 1 year	Av. for all counties
Uton	3141	126.8	91.5	150.0	86.7	85.4	108.2	102.4	107.3
Swedish Select	134	119.7	88.2	138.8	64.8	90.4	89.2	97.2	98.3
Markton	2053	122.3	97.9	149.5	78.0	94.9	114.9	106.3	109.1

*Yield data on Uton and other varieties and selections also have been recorded by Coffman. (See footnote 5.)

TABLE 7.—*Average percentage of loose and covered smut infection, Logan, Utah, 1937–40.*

Smut species	Swedish Select	Markton	Uton
U. avenae (Wash.)	37.5	0.25	0.12
U. avenae (Utah)	41.0	0.25	0.38
U. levis (Wash.)	48.9	0.10	0.03

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BARLEY VARIETIES REGISTERED, VI[1]

H. K. HAYES[2]

ONE variety of barley was approved for registration in 1939[3] making eight varieties registered previous to this report. Three varieties were approved for registration in 1940.

WINTEX, REG. NO. 9

Wintex is intermediate in growth habit between true winter and true spring barley and is adapted to either fall or spring seeding. It is somewhat less winter hardy then Tennessee Winter in trials conducted under the leadership of the Bureau of Plant Industry, U. S. Dept. of Agriculture, but has proved about as winter hardy in north central Texas as Tennessee Winter. The six-rowed, awned spike is slightly longer than that of Tennessee Winter and averages more kernels per head. The superior characters of Wintex include high yielding ability, high test weight, strong straw, and its high carrying capacity when used for fall and winter pasture.

It is a selection made at Denton, Tex., in 1931, by I. M. Atkins from a strain of barley named Smith. It was first distributed in the fall of 1939.

Yields in bushels per acre of Wintex, Tennessee Winter, and a local variety named Finley are given in Table 1.

TABLE 1.—*Comparative yields in bushels per acre of Wintex and other varieties of barley at Denton, Texas, in field plots, with four replications, 1936–39, inclusive.*

Variety	Yield in bushels per acre				
	1936	1937	1938	1939	Average
Wintex	35.4	63.6	58.5	48.0	51.4
Tenn. Winter, C.I. 3545	33.8	49.8	41.2	34.9	39.9
Finley (Local), C.I. 5901	21.7	45.5	41.9	46.0	38.8
Tenn. Winter, C.I. 6125	27.3	44.7	40.8	32.4	36.3

COMPANA, REG. NO. 10

Compana is a two-rowed, hulled, semi-smooth awned barley with a short, erect habit of growth. Its valuable characteristics include high yielding ability, early maturity, resistance to drought, and greater resistance to grasshopper attack than Horn and Trebi. It was selected from a composite cross made in 1920 by Dr. H. V. Harlan. It is the product of cooperative investigations by the Bureau of Plant In-

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 26, 1940.

[2]Chief, Division of Agronomy and Plant Genetics, Dept. of Agr., Univ. of Minn., St. Paul, Minn. Member of committee on Varietal Standardization and Registration of the Society charged with the registration of barley varieties.

[3]HAYES, H. K. Barley varieties registered, V. Jour. Amer. Soc. Agron., 32:84. 1940.

dustry, U. S. Dept. of Agriculture, and the Montana Agricultural Experiment Station.

Comparative yields of Compana, C.I. 5438, and the two varieties of barley, Trebi and Horn, recommended for Montana are given in Table 2. The nursery trials at Judith Basin Branch Station were made in triplicated three-row plots, the field trials were made in 1/56 acre plots, with four replications, and the Huntley Experiment Station trials were made in duplicate 1/10 acre plots. The trials under irrigation were made in triplicate three-row plots and in triplicate 1/56 acre plots.

TABLE 2.—*Comparative average yields, in bushels per acre, of Compana, Trebi, and Horn in various trials in Montana.*

Variety	C.I. No.	Dry land			Irrigated	
		Judith Basin Branch Station		Huntley Exp. Sta.	Bozeman	
		Nursery, 1932–37	Field plots, 1935–39	Field plots, 1939	Nursery, 1936–39	Field plots, 1939
Compana....	5438	19.3	24.4	71.4	73.9	86.1
Horn.......	926	14.5	20.2	49.1	64.4	81.5
Trebi.......	936	18.9	21.7	—	61.4	102.4

BARBLESS, REG. NO. 11

Barbless is a lax, six-rowed, hulled, smooth-awned barley, resistant to stripe disease, *Helminthosporium gramineum* Rabh., with high yielding ability, maturing 4 or 5 days later than Oderbrucker. It was first distributed by the Wisconsin Experiment Station in 1929 and has been grown extensively under the name Wisconsin No. 38 throughout the north central barley production area of the United States. While not equal to Oderbrucker in malting, it is the main

TABLE 3.—*Comparative yields, in bushels per acre, at Madison, Wisconsin, of Barbless and Oderbrucker, 1930–39, inclusive.*

Year of test	Barbless	Oderbrucker
1930..........	45.5	41.5
1931..........	37.8	39.5
1932..........	55.5	34.9
1933..........	29.0	25.1
1934..........	16.4	14.1
1935..........	48.6	38.8
1936..........	18.9	16.1
1937..........	26.6	17.5
1938..........	32.9	17.7
1939..........	23.6	25.0
Average, 10 years..........	33.5	27.0

variety used for that purpose in Wisconsin and Minnesota. It was produced by B. D. Leith from a cross of Oderbrucker × Lion made in 1917.

Comparative yields of Barbless, Ped. 38, C.I. 5105, and Oderbrucker are given in Table 3.

REGISTRATION OF IMPROVED WHEAT VARIETIES, XIV[1]

J. ALLEN CLARK[2]

THIRTEEN previous reports present the registration of 62 improved varieties of wheat. In 1939, four varieties were registered.[3] Two varieties have been approved for registration in 1940.

Varietal Name	Reg. No.
Marmin	328
Rival	329

MARMIN, REG. NO. 328

Marmin (Minn. 2614, C.I. 11502)[4] was developed in cooperative experiments of the Minnesota Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. It is the result of a Minturki (winter) × Marquis (spring) cross made at the Minnesota Agricultural Experiment Station in 1922.

Marmin is a winter wheat with glabrous, white glumes, awned spike, and semihard to hard red kernels. It is equal to Minturki in winterhardiness and disease resistance. It was developed and distributed chiefly for improved quality. At University Farm and Waseca, for the 6-year period, 1935–1940, it yielded slightly less than Minturki, but was superior to Minturki with respect to weight per bushel, hardness of grain, and crumb color of the loaf of bread. Also the carotenoid pigment content of the grain was less than that for Minturki. In each of these characteristics it was equal to or better than Minturki in every year in which they were determined.

Details are presented in Table 1. The variety was named and distributed to farmers for fall seeding in 1940. There were about 1,300 bushels available and all of this was seeded. For further information on the distribution of Marmin wheat, see the *Minnesota Seed Grower* for August 1940.

RIVAL, REG. NO. 329

Rival (N. Dak. Ns. 2634, C.I. 11708) was developed from a cross between Ceres and Hope-Florence made in 1929 at the North Dakota Agricultural Experiment Station, Fargo, N. Dak. The selection was made in 1933 and was entered in the Uniform Regional Nursery in 1935 and in plot experiments at the North Dakota stations in 1936.

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[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication January 8, 1941.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1940 Committee on Varietal Standardization and Registration of the Society, charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, XIII. Jour. Amer. Soc. Agron., 32:72–75, 1940.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

TABLE 1.—*Average yield per acre, bushel weight, texture of grain, color of loaf, and carotenoid pigment content of Marmin and Minturki grown in 1/40-acre plots at University Farm and Waseca, Minn., 1935 to 1940.*

Variety	1935	1936	1937	1938	1939	1940	Average	Percentage of Minturki
				Yield per Acre, bu.				
Marmin (New)	43.8	29.6	16.2	20.4	44.3	47.5	33.6	96.6
Minturki (Standard)	44.4	30.7	17.8	22.3	41.3	52.5	34.8	—
				Bushel Weight, lbs.				
Marmin	61.9	58.3	56.4	56.0	57.8	61.6	58.7	102.8
Minturki	59.6	55.7	53.4	54.8	57.3	61.5	57.1	—
				Texture of Seed, % Hardness				
Marmin	78	65	67	75	71	78	72	107.5
Minturki	68	62	67	69	69	68	67	—
				Crumb Color of Loaf of Bread, Percentage Score				
Marmin	97.8	97.0	97.6	97.6	98.3	—	97.7	101.7
Minturki	94.3	94.0	97.4	97.1	97.8	—	96.1	—
				Carotenoid Pigment Content, p.p.m.				
Marmin	—	2.63	—	3.33	4.03	—	3.33	80.2
Minturki	—	3.84	—	3.93	4.67	—	4.15	—

Rival is a bearded spring wheat. The plant is midseason and midtall and the kernels midlarge to large and hard. It has produced higher average yields than Thatcher at the North Dakota stations and is more resistant to leaf rust.

TABLE 2.—*Annual average yields of Rival and Thatcher wheats grown in plot experiments at the Fargo, Langdon, Mandan, and Dickinson, N. Dak., stations, 1936–1940.*

Variety	1936*	1937	1938	1939	1940	Average	Percentage of Thatcher
Rival (new)	8.4	21.9	23.8	19.4	15.9	17.9	105.9
Thatcher	7.9	19.8	19.3	20.5	16.8	16.9	—

*Mandan and Dickinson yields not included because of near failure from drought.

Nearly a thousand bushels of Rival was distributed to North Dakota wheat growers in 5-bushel lots in the spring of 1939. Dr. L. R. Waldron, the breeder, applied for registration. The yield data upon which registration was based are presented in Table 2. For further information on Rival wheat, see the Bimonthly Bulletin of the North Dakota Agricultural Experiment Station (Vol. 1, No. 3, 1939).

REGISTRATION OF IMPROVED SORGHUM VARIETIES, II[1]

R. E. Karper[2]

TWO improved varieties of sorghum were approved for registration in 1940,[3] as follows:

Variety	Reg. No.
Coes	77
Highland	78

COES, REG. NO. 77

Description.—Plants very early, mid tall; stems slender, juicy, not sweet; tillers freely; branches sparsely; narrow leaves, *8 to 10* in number; opaque midrib; sheaths overlapping; panicles erect, long, cylindrical, semi-loose; rachis nearly continuous; glumes compressed, open at tips when ripe, straw to reddish color; lemmas awned; stigmas white; kernels covered by glumes, thresh free, small, slightly flattened, creamy white color; endosperm starchy and corneous.

Coes is a dual purpose sorghum originated and distributed from the Akron, Colo., U. S. Dry Land Field Station and the Colorado Experiment Station by J. F. Brandon and F. A. Coffman from a selection from Modoc sorghum, probably originally a cross between Early Pink kafir and Freed. The name Coes is derived from a contraction of Cope and Joes, two inland trading posts in northeast Colorado.

The variety is early maturing and well adapted to the higher altitudes and northern latitudes of the sorghum region. It does not shatter but threshes free from the seed. Coes is susceptible to smut but resistant to "weak-neck" disease.

Comparative yields of Coes (C.I. No. 1104) and other varieties tested at Akron, Colorado, during the 5-year period from 1933 to 1937 are given in Table 1.

Table 1.—*Yields in bushels per acre of Coes and other varieties of sorgum tested at Akron, Colo., 1933–37, inclusive.*

Varieties	1933	1934	1935	1936	1937	Av.
Coes	17.4	1.7	24.8	17.4	13.7	15.0
Dwarf Freed	16.9	1.0	21.7	15.3	8.9	12.8
Sooner	10.9	1.2	21.5	21.0	7.1	12.3
Cheyenne	12.8	1.3	22.7	14.8	7.7	11.9
Freed	10.1	1.0	23.2	12.9	6.8	10.8
Greeley	12.0	1.7	11.5	22.6	5.4	10.6

[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication January 20, 1941.

[2]Agronomist in Charge of Sorghum Investigations, Texas Agricultural Experiment Station, Lubbock, Tex. Member of the 1940 Committee on Varietal Standardization and Registration of the Society charged with the registration of sorghum varieties.

[3]Three varieties were approved for registration in 1936. (See this Journal, Vol. 30, pages 306–308.)

HIGHLAND, REG. NO. 78

Description.—Plants early, mid tall; stems medium, taper upward, juicy, not sweet; tillers freely; leaves medium wide, *8 to 10* in number, opaque midrib; sheaths overlapping; panicles erect, long, cylindrical, loose, long rachis; glumes compressed, straw to reddish-brown color; mid short; lemmas awnless, stigmas white; kernels chalky white, reddish-brown spots; endosperm starchy and corneous.

Highland is a dual purpose sorghum originated and distributed from the Akron, Colo., U. S. Dry Land Field Station and the Colorado Experiment Station from head selection from Dawn kafir, C.I. No. 340, in 1920 by, J. J. Curtis, J. F. Brandon, and F. A. Coffman. Highland is named after a deceased neighbor of the Akron Station who was a staunch supporter of the Station's work.

The variety is early and well adapted to the highland section of the Central Great Plains, outyielding such other varieties as Sooner milo, Freed, Early Kalo, and Colby. It does not shatter but threshes free from the seed. Highland is susceptible to smut but resistant to "weak-neck" disease.

NOTES

FERTILIZER DISTRIBUTOR FOR FACTORIAL DESIGN EXPERIMENTS[1]

CONDUCTING potato fertilizer experiments with the equipment ordinarily used involves considerable labor. It is necessary to empty the fertilizer hopper with every change in fertilizer. This work can be reduced by making all the plantings with a given fertilizer before changing to another, but this requires much extra travel about the field, especially when extensive experiments are involved which necessitate the use of extra land for getting from one plot to another or driving the machine over land already planted.

The introduction of factorial design has tended to increase the number of fertilizer treatments included in such an experiment with a consequent increase in the number of fertilizer changes that must be made. To overcome these difficulties and simplify the installation of such experiments, a fertilizer distributor was designed which does away with the necessity of emptying the hopper and which makes possible the continuous planting of an experiment regardless of the number of fertilizer treatments involved.

The apparatus herein described was used at the Long Island Vegetable Research Farm at Riverhead, New York, to install several potato fertilizer experiments, one of which included 27 different fertilizer mixtures. It was also used on four other farms in 1940 to install less complicated potato fertilizer experiments and this use greatly simplified the work as compared with previous methods.

The fertilizer hopper of a single-row potato planter was divided into three compartments each of which was fitted with a gate which could be regulated to deliver given quantities of fertilizer materials. One of these compartments carries a mixture of nitrogenous materials; the second carries superphosphate; and the third carries the potash supply. As the delivery from each compartment can be regulated independently, it is possible to obtain any desired mixture within the capacity of the machine. A single belt revolving beneath the hopper serves all three compartments; so it was necessary to provide slides that could be inserted to cut off the flow when it was desired to omit one of the elements.

The machine was originally provided with a single gate approximately 7 × 7 inches which regulated the delivery of fertilizer by its distance above the belt. This single gate was replaced by three gates each 2 × 7. (See Fig. 1 for details of construction.) A hole was bored in the center of each gate and this was tapped to take a ½-inch iron bolt which was screwed firmly into the gate and fastened with a locknut. These bolts are approximately 2½ inches long and extend through slots in the front wall of the hopper to provide attachment for the control levers. Care was taken to eliminate looseness in the movement of the gates and in the levers that control them. The two partitions extend below the hopper to the surface of the belt to pre-

[1]Paper No. 234, Department of Vegetable Crops, Cornell University, Ithaca, New York.

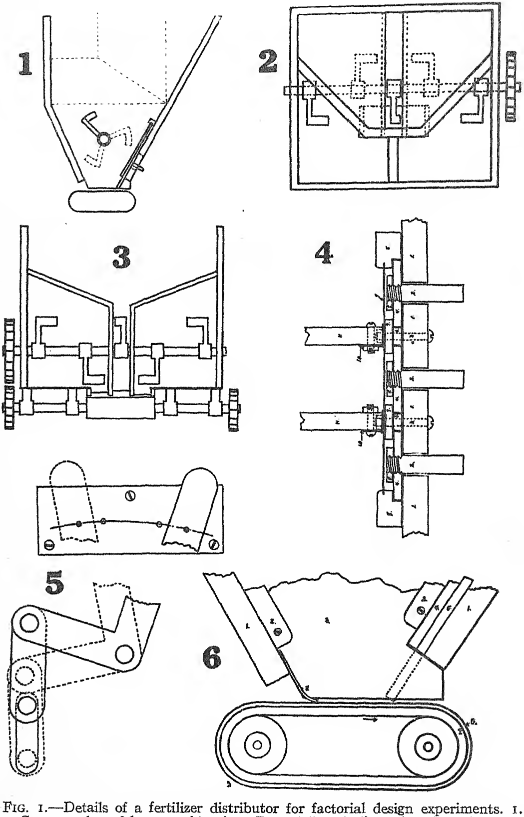

FIG. 1.—Details of a fertilizer distributor for factorial design experiments. 1. Cross section of hopper, side view. Dotted lines indicate location of middle compartment and distribution of agitator arms about the shaft. 2. Top view of hopper. The dotted rectangle indicates location of the three gates. 3. Cross section of hopper, front view. The upper compartment feeds directly to the middle gate; the agitators in the side compartments move the materials toward the belt. 4. Details of the gate construction. The gates are pieces of steel

vent a sidewise flow of materials. The agitator for the middle compartment was cut down to fit the narrow space between the two partitions.

It is necessary to calibrate such a machine just before use as the flow of fertilizer materials is readily affected by weather conditions. The following method was used: at each calibration a block of hardwood was fastened to the hopper beneath the upper end of each control lever. Each lever was provided with a small projection which rested against the block with slight pressure. The lever was moved across the block until the opening of the gate allowed the passage of the desired quantity of material. The point where the projection rested against the block was then marked and the other points located in this same way. After all these points had been marked, a number of trials were run, shifting from setting to setting. When the deliveries had been carefully checked, a small hole was bored at each of the points marked on the blocks. The pressure of the lever against the block caused the projection to drop into the holes as the lever was shifted across the block; a slight outward pressure on the lever released it. With only two or three holes in each block, changes can be made so rapidly that it is not necessary to stop the machine when planting. The gates are located so close to the front of the belt that changes in the quantity of material delivered are made with very little forward travel of the machine.

The hopper was raised about 6 inches to provide more opportunity for the three streams to mix as they flowed downward through the delivery tubes. This extra space provides room for inserting three receptacles for receiving the deliveries when calibrating the machine.

Some difficulty was experienced in getting satisfactory mixtures for supplying the nitrogen and the potash. Granular superphosphate, 20% P_2O_5, flowed freely under all conditions encountered during the 1940 planting season. A mixture made up of 300 pounds of nitrate of soda, 150 pounds of uramon, and 100 pounds of castor pomace proved satisfactory, although it did not flow with equal freedom at all times. Muriate of potash, 60% K_2O, flowed so freely under dry conditions that it was necessary to dilute it to get the small quantities of potash required for some of the experiments. Under moist conditions, the muriate by itself gave very irregular deliveries. A mixture made up of 100 pounds of the muriate, 50 pounds of dry sand, and 50 pounds of ground cocoa shells flowed freely at all times.

2x7x¼ inches. The gates are separated by strips of steel ½ inch wide. Over each of these there is a strip of steel one inch wide to hold the gate in place and to provide a channel in which it can move. The wooden strips which served these purposes for the single gate were retained, as is shown in the cut. A sheet of galvanized iron covers the gate assembly. Strips of galvanized iron bent at right angles are bolted to the gate assembly and to the rear wall of the hopper to provide fastening for the partitions which are made of plywood, one-half inch thick. 5. Details of the control levers. The holes in the control levers and in the connecting links are fitted accurately to the bolts to avoid looseness and the bolt on which the lever rotates is placed to provide movement in line with the travel of the gate. 6. Details of partition showing location in reference to the belt, method of fastening to gate assembly and to rear wall with galvanized "angle irons", strip of rubber at rear of hopper to prevent backward flow of materials, and approximate location of gates to the front of the belt.

A potato fertilizer experiment in factorial design with nitrogen applied at the rates of 60, 90, and 120 pounds to the acre; phosphoric acid at the rates of 120, 160, and 200 pounds to the acre; and potash at the rates of 80, 140, and 200 pounds to the acre, was planted with this machine. All possible combinations of these three quantities of the three elements, 27 in all, were included in the experiment which was planted on 486 three-row plots. Although 2,384 changes of the control levers were made while planting this experiment, the time required for the planting was very little more than would have been required if but a single fertilizer had been used. It is not necessary to stop the machine for changes that require moving only one or two levers.

It was the intention to make a machine with a number of hoppers that could be operated independently of each other but being unable to obtain the type of hopper desired the machine on hand was altered as described. For experiments involving more factors, separate hoppers would be required, but for the purposes for which it was designed this machine works very well.

Fig. 1 shows the division of the hopper into three compartments, the location of each, and gives details of the gate assembly, the control levers, and the partitions.—P. H. WESSELS, *Long Island Vegetable Research Farm, Riverhead, N. Y.*

DEFEATISM IN AGRONOMY

NOT long ago this writer forwarded to the presidents, deans, and leading agronomy professors of the agricultural colleges and to the directors of the experiment stations a communication entitled, "The education of an agrobiologist; an address to the directing heads of agricultural instruction in the United States". This communication evoked numerous responses. The drift of comment by the agronomists is more or less fairly represented by the one reproduced below, which is from a Research Professor of Agronomy in a New England state college:

"I would like to raise some objections of a practical nature which to me would seriously hinder any general, practical application of the principles you have outlined. You state: 'An environment that has been standardized in respect to unit space, temperature, moisture, etc. . . . .' which unfortunately does not exist under practical field conditions. The most important disturbing element, particularly in New England, is the weather. We have no means whatsoever of determining what the weather will be one season to the next, and this may be the most important factor influencing crop yields. I recall a statement made by Professor Bender of the New Jersey Station a year ago to the effect that an experimental plot of Ladino clover yielded 25 tons of green forage to the acre one year and the next year, a drought year, the same area yielded 5 tons of green forage to the acre. How can such a variation as this be accommodated in any mathematical formula? In areas where the climate is tempered by great bodies of water, and where natural soil fertility conditions are very low, I can understand where agrobiology would work out fairly

well. In the sugar cane producing areas it is my understanding that weather conditions vary little from season to season and the soils are so thoroughly leached that plant growth response is almost completely related to the kind and amount of fertilizing materials which are applied.

"Other serious difficulties are soil heterogeneity and inherent strain and variety variation in different species of forage crops, particularly in the naturally fertilized forage crops.

"I will be glad to receive your comments on my objections to the practical application of the principles of agrobiology."

The following reply was sent, and may be taken as a response to other agronomists who have favored me with similar objections:

"Many of the agronomists who have commented on my address seem to be hazy on the relations of agrobiologic science and agrobiologic practice. The purpose of the pure science is to establish the immutable relations between the factors involved; the job of the practician is to adjust the factors and the materials at his disposal in the manner best calculated to approximate the ideal condition which the pure science has indicated. But to approximate this condition the practician must have a clear conception of the ideal toward which he is working and an adequate knowledge of the things he is working with, together with a resolute determination to reduce opposing circumstances to their least possible dimensions. He may be excused for failure to control the uncontrollable, but not if he allows himself to be bluffed by circumstances that have known or ascertainable values, or if he assumes a defeatist attitude in the face of difficulties which he has not taken the trouble to measure.

"What if there are uncontrollable circumstances, among which you designate the weather as the most important? That will be no excuse for neglecting to measure controllable circumstances, including the other serious difficulties that you list: soil heterogeneity and inherent strain and variety variation in different species. Every competent agrobiologist knows what to do about *them*. The characteristic attitude of the agrobiologically informed agronomist is that while the weather will have its way, no measureable factor will be allowed to take adverse toll of the due yield of species whose requirements and capabilities have been ascertained beforehand. But this deference to the weather is not extended to controllable moisture conditions.

"For the past dozen years I have been encountering this defeatist attitude in numerous and in some cases unexpected quarters, and in other connections I have expressed myself on the subject at considerable length. If the library of your institution possesses a copy of my book "Nations Can Live at Home" (New York: Norton, 1935), and if you will read through pages 105–113, you will find, in a passage of some 2,500 words, a succinct analysis of all the difficulties you have raised (and others), including the question you pose as to how climatic variations may be (and are) accommodated in a working mathematical formula."—O. W. Willcox, *197 Union Street, Ridgewood, N. J.*

A SATISFACTORY SUPPORT FOR CEREALS GROWING IN POTS

CEREAL plants grown to maturity in pots require some kind of support to prevent them from falling or breaking over. Plants tied to bamboo poles or wooden stakes are kept upright, but they are shaded by the stakes and the tying is laborious.

A single galvanized wire stake and a movable wire loop for each pot have proved to be a very satisfactory method for supporting cereal plants during the past 5 or 6 years. Very little shading is evident and tying or stringing is unnecessary. The galvanized wire stakes are made of No. 10 stiff steel wire 42 inches long. Shorter and longer lengths also are obtainable. These wires, which can be pur-

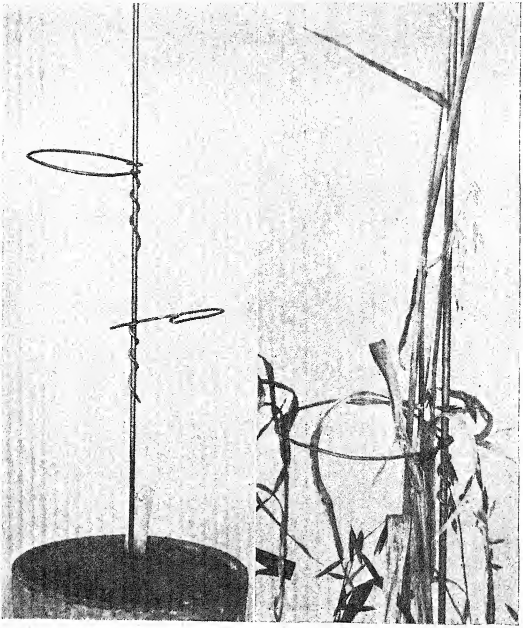

FIG. 1.—Left, closed and open loops attached to the supporting wire; right, plant inclosed in loop.

chased from nursery supply houses at about $15 per thousand, are durable and easy to store and handle.

The best of several methods tried for fastening the plants to the supporting wire is that of using wire loops as shown in Fig. 1. The loops are moved upward as the plants grow. The loops can be made of soft No. 14 wire by any greenhouse laborer. They last several years and cost very little. The loops may be strung on a wire for storage.—J. W. TAYLOR and F. A. COFFMAN, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

A POSSIBLE NEW METHOD FOR THE CONTROL OF POLLINATION OF CORN

IN 1938, on the South Dakota Experiment Station Agronomy Farm, a method was tried by the writer for controlling pollination in corn with the use of "overall bags" constructed from heavy muslin, of specified weight and quality. The bags were placed over the corn plants previous to time of silking. Fig. 1 shows one of the "overall" bags in place, in this case over two stalks of corn in a single hill, one detasseled.

The outcome in 1938, indicated that the overall bags had been placed over the plants too early in their stage of growth and with too much defoliation, with the result that pollination was inhibited in a high percentage of cases, though not all, in this first year.

A larger number of trials were made in 1939, with more careful attention to placing the "overall bags" over the plants not too long before emergence of silk and also with less previous defoliation of the plant. Satisfactory controlled pollination occurred in 75% of the hills thus covered in the second year.

Again, in 1940, the method was used on a still larger number of plants. Tassels were removed from half the number to have them serve as checks against the plants where the bags were placed without removing the tassels. In 1940, check plants of a white variety were utilized in a yellow field so that the effect of yellow or white pollen on supposedly white endosperms could be observed.

FIG. 1.—An "overall" bag placed in position over a corn plant to control pollination.

Desirable precautions to be observed are as follows:

1. Place the "overall bag" over the corn plants at the optimum stage of growth, presumably as short a time as practicable before emergence of silks.
2. Remove just sufficient foliage from the plant before placing the bags to permit the pollen to fall upon the silks but not to inhibit growth.
3. Become skilfull in clipping back the tips of the ear-shoots to expose the silks at the exact moment when they become protected from outside pollen by the "overall bag" covering.

With the use of the foregoing precautions, the results from the "overall method" for controlling pollination in corn were encouraging. The time computed per plant for using this method was one-half as great as that required for other methods commonly employed. Study of this method and its effectiveness will be continued.—A. N. HUME, *South Dakota Agricultural Experiment Station, Brookings, S. D.*

RUSSIAN WILD-RYE, *ELYMUS JUNCEUS* FISCH[1]

RUSSIAN wild-rye (*Elymus junceus* Fisch.) is a promising new grass for use in erosion control and for pasture in the northern Great Plains. One of the early introductions of this species is F.P.I. 75737 obtained by the Division of Plant Exploration and Introduction from the Western Siberian Experiment Station, Omsk, U.S.S.R., in 1927. The seed was distributed by the Department to various stations in 1928, and has been grown at the Northern Great Plains Field Station, Mandan, North Dakota, since that time. Most of the seed now grown originated from that introduction. Later introductions from U.S.S.R. were made in 1934 and 1935 by the Westover-Enlow Expedition.

The species is a drouth-resistant, widely variable, bunch type grass with erect culms, terminal spikes, and an abundance of basal leaves. Growth starts early in the spring and seed is matured before that of most other grasses; however, growth continues throughout the growing season until late in the fall. It has the ability to make growth after frequent clippings, but because of this characteristic it should be managed carefully under grazing so as not to deplete the root reserves to a point where the grass will be injured. Hay yields from 42-inch rows at Mandan, N. D., since 1937 indicate that the species will yield as well as other grasses. Seed yields from row plantings have been from 200 to 400 pounds per acre, but when planted in rows for seed production the culms tend to break and lodge. The seed shatters rapidly after maturity but threshes and cleans easily; however, because of the short, sharp awn and stiff hairs on the lemma and palea it must be processed before it will flow freely through a drill.[2]

[1]Cooperative investigations of the Division of Forage Crops and Diseases, and the Division of Dry Land Agriculture, Bureau of Plant Industry, and the Nursery Division, Soil Conservation Service, U. S. Dept. of Agriculture.

[2]WEBER, G. L. A method of preparing some native grass seeds for handling and seeding. Jour. Amer. Soc. Agron., 31:729–733. 1939.

Breeding and selection work has been carried on with the species since 1936 at Mandan, N. D., and improved strains have been developed which are now ready for seed increase. Seed is not produced until the second year of growth, therefore strain building is slow. Preliminary studies of mode of pollination indicate that the species is naturally cross pollinated to a greater extent than some species of the genus but not to the degree of many perennial grasses. In 1939, approximately 30% as much seed was produced under parchment bags on 41 plants as was produced by open pollination. The variation in amount of selfed seed produced on different plants varied from none to more seed being produced under bag than under open pollination. Other workers have reported difficulty in securing selfed seed, however. First generation progenies from selfed seed in general show no loss of vigor, although some lines show a marked decrease in vigor. Progenies from two generations of selfing vary also as to loss in vigor, some lines showing marked loss of vigor and other lines no loss. Uniformity of plants within some lines is increased by selfing; in others marked lack of uniformity is shown in second generation selfed lines.

Most rapid improvement in strains has been secured by selection under open pollination. Characters selected for have been qualitative in most cases. Strain 19-55 has been developed entirely under open pollination. It has resulted from mass selection within the progeny of a single plant. Fig. 1 shows a typical plant of this species, and Fig. 2 shows the mother plant from which the improved strain was developed.

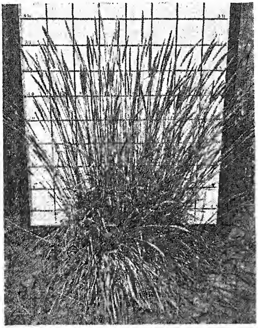

FIG. 1.—A typical plant of Russian wild-rye.

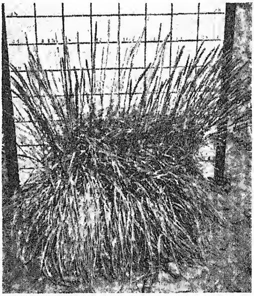

FIG. 2.—The mother plant of Russian wild-rye from which strain 19-55 was developed.

The new strain has two improved qualities. One is resistance to breaking and lodging because of shortened culms, and the other is

increased leafiness, with the leaves higher on the culms. Other strains, developed by mass selection, show improvement in leafiness, resistance to lodging, and uniformity. Some of these are considerably later in maturity. These improved strains are now ready for seed production and further testing.—George A. Rogler, *Mandan, North Dakota.*

BOOK REVIEWS

SOILS AND SOIL MANAGEMENT

By A. F. Gustafson. New York: McGraw-Hill Book Co. 415 pages, illus. 1941. $3.

THIS work is a fitting help for the student of soil, and of soil management as it is a practice on the farm or a study in the classroom. Consequently, the soil and its agronomic aspects are not treated wholly from the viewpoint of the pedologist, the botanist, or the strict scientist. Illustrations are drawn from farm practices and farmer experience. Modern science of the soil is, however, by no means disregarded. The use of such concepts as carbon-nitrogen ratio, colloidal adsorption, base exchange, micro-organisms interacting with clay, is recognized in simple, clear, and effective presentations. Their explanation and elucidation are not the author's intention, but rather the presentation of practices based on them so as to permit crop production with soil conservation at the same time.

Conservation of the soil through wise cropping and management for reduction of plant nutrient losses and for increased fertilization is discussed rather than practices for conservation itself. Water conservation and its wise use by different crops through proper soil management are given space sufficient for those interested in this aspect. Conservation of the body and fertility of the soil runs well through the entire text to illustrate the author's concern as was well presented in his previous publications.

The style is direct, the presentation is clear, and self-explanatory terms are common, so that reading is easy.

For students not readily attracted by the more academic presentations there should be much of interest and help in these 400 pages treating the subject of the soil and its management. (W.A.A.)

AGRICULTURE IN UGANDA

Edited by J. D. Tothill. London: Oxford University Press. XVI+ 551 pages, illus.+4 folding maps. 1940. 20 s net.

THIS book is an official publication compiled from original contributions by the staff of the Uganda Department of Agriculture. Its purpose is to furnish an account of the agriculture, crop industries, and food supplies of the Uganda Protectorate. It contains very interesting accounts of climate and soil, the handling of crops, soil maintenance, and conservation. Since cotton is a main crop of Uganda special attention is paid to methods of handling it for high quality and yield. Considerable space is given, however, to many other crops such as bananas, sweet potatoes, cassava, cereals (some common ones and others unfamiliar to American agriculture), coffee and tea, cacao, and rubber. Many other crops are also covered, including fruits and vegetables. Even bee-keeping and the locust pest receive a small section of the book. A comprehensive picture is thus given of the whole agriculture of the Protectorate. The last section of the book deals with agricultural education in Uganda.

Since small type is used thruout, the wealth of material really constitutes a handbook of the subject. Anyone in any way interested in how the other half of the world farms and the many unfamiliar as well as familiar crops it grows, will find this volume not only intensely interesting but also very instructive. This should be especially true of any agricultural worker who deals with many of the crops covered. (R.C.C.)

OUTLINES OF STRUCTURAL GEOLOGY

By E. Sherbon Hills. New York: Nordeman Publishing Company, Inc. IX+172 pages, illus. 1940. $2.25.

THE author of this little volume is lecturer in geology in the University of Melbourne. The aim of the book, according to its author, is a brief, reasonably complete, and well-documented summary of the subject, aimed primarily at the field geologist. Many references are given at the bottom of the pages for further reading and it is well illustrated mainly by sketches and diagrams. It is written largely from the Australian standpoint, with illustrations, however, from many parts of the world. A third of the volume deals with folds and faults with chapters also on structure of igneous rocks and petrofabric analysis.

Agronomists, geologically inclined, will find the book interesting and instructive. (R.C.C.)

AGRONOMIC AFFAIRS

STATE REPRESENTATIVES

ACTING jointly, Dr. L. E. Kirk, President of the American Society of Agronomy, and Dr. Charles E. Kellogg, President of the Soil Science Society of America, have designated the following persons to serve as representatives of the two societies in their respective states for the purpose of stimulating interest in and procuring new members for the two organizations. The representatives for the American Society of Agronomy are also requested to act as "correspondents" for the JOURNAL, supplying items of general interest to agronomists, particularly changes in personnel, and other news items.

STATE	AMERICAN SOCIETY OF AGRONOMY	SOIL SCIENCE SOCIETY OF AMERICA
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Arkansas	R. P. Bartholomew	L. C. Kapp
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Colorado	W. H. Leonard	Alvin Keser
Connecticut	M. F. Morgan	M. F. Morgan
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Georgia	W. O. Collins	W. O. Collins
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Nebraska	F. D. Keim	M. D. Weldon
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South Dakota	A. N. Hume	G. A. Avery
Tennessee	C. A. Mooers	Eric Winters
Texas	Ide P. Trotter	Ide P. Trotter

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Virginia	S. S. Obenshain	S. S. Obenshain
Washington	E. G. Schaffer	S. C. Vandecaveye
West Virginia	Edward H. Tyner	G. M. Browning
Wisconsin	Emil Truog	Emil Truog
Wyoming	T. J. Dunnewald	T. J. Dunnewald
Canada	J. B. Harrington	F. F. Morwick

NEWS ITEMS

The Conservation and Survey Division of the University of Nebraska has just published a well-illustrated bulletin from the Department of Botany entitled "Native Midwestern Pastures: Their Origin, Composition, and Degeneration" under the authorship of J. E. Weaver and W. W. Hansen.

The marked increase in advertising in this number of the Journal is due in large measure to the efforts of our advertising representatives, Macfarland & Heaton of New York City. Several former advertisers as well as new accounts have joined the "old standbys" in this issue, and we hope will continue to use the Journal. We urge all readers of the Journal to peruse the advertising pages and to patronize our advertisers whenever it is possible to do so.

Doctor Michael Peech, formerly with the Citrus Experiment Station, Lake Alfred, Fla., has been appointed Professor of Soil Technology, Cornell University, to fill the position vacated by the death of Doctor B. D. Wilson.

Doctor Robert E. Yoder was appointed Chief in Agronomy at the Ohio Agricultural Experiment Station in January of 1941. Dr. Yoder was graduated from Ohio State University in 1928, and gained the Ph.D. degree in Soils in 1932. For seven years he was located at the Alabama Polytechnic Institute, first as Assistant Professor of Soils, then as Assistant Professor of Agricultural Engineering and Acting Head of the Department of Agricultural Engineering. In 1939 he returned to Ohio as Associate in Administration at the Experiment Station and Cooperative Agent in Research in the Soil Conservation Service.

Byron T. Shaw, who received his Ph.D. degree at the Ohio State University in March of 1940, returned in October as Assistant Professor of Agronomy at Ohio State University and Assistant in Agronomy at the Ohio Agricultural Experiment Station. He succeeds Dr. L. D. Baver. Since receiving his doctorate degree Dr. Shaw had been Instructor in the Truck Crops Division of the University of California.

According to information supplied by *Biological Abstracts*, 605 contributions to the field of bioclimatology were summarized during 1940 as a result of the first complete year of reporting research in this field. The Bioclimatology-Biometeorology section proper reported 234 contributions from 127 current periodicals and reviewed 31 books.

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EFFECTIVE USE OF SCIENCE IN CROPS RESEARCH[1]

Noble Clark[2]

SIR Josiah Stamp has said that the standard of living in civilized countries increased more than four times during the past hundred years. It was science and technology that made this possible.

While the world may not appreciate it, the fact remains that the marvelous material advance which occurred during the last three or four generations came about almost entirely through discoveries made by men of science. The achievements by the Greeks 2,000 years ago in architecture, in philosophy, in sculpture, and in literature, are still the standards of excellence for evaluating present-day developments in these fields. No one has yet succeeded in formulating a religion that surpasses what Jesus taught 20 centuries ago.

But it is not so in the case of knowledge of the natural world. During the lifetime of many of us here today, there have been more additions to man's understanding and control of nature than occurred in all the previous generations of humanity. The results that have followed this increase in scientific knowledge, and the advances thereby made possible in technology, will be recited by historians of the future long after the soldiers and the rulers of our generation are forgotten. For not only has the new knowledge greatly improved man's material welfare and comfort, but it has also given him an enormously wider intellectual outlook. Traditions, superstitions, fears, beliefs based on authority rather than evidence; these, and a host of other barriers to freedom of the mind and of the spirit, have been largely swept away in our part of the world with the advance of science and the acceptance of the methods of science.

Before the flowering of present-day science and technology, each generation thought it did things as they had always been done. Changes in methods were so gradual they were not apparent in a single lifetime. Now we have a wholly new attitude. Systematically we search for the new knowledge that will enable men to shape the world closer to their needs and their desires. In Franklin's time,

[1]A statement before the Crops Section of the American Society of Agronomy at the annual meeting held in Chicago, Ill., December 6, 1940.

[2]Associate Director, Wisconsin Agricultural Experiment Station, Madison, Wis.

scientific investigations were the hobby of a few amateurs who had a lot of curiosity and a fondness for experiments with physical things. Today there are tens of thousands of men and women throughout the world who are devoting their lives to scientific research, an enterprise that has become the most fruitful and influential of all human activities. A. N. Whitehead has said that the greatest invention of the 19th Century was the invention of the method of invention. The occasional genius, or occasional lucky thought, was replaced by organized, systematic research. Truly, it can be said that research is the seed of all new economic life.

Agricultural research, particularly in the field of crop production, has played a primary role in the advance in human welfare made possible by the use of science. It was not until man learned how to increase food supplies more rapidly than the rate of growth of the population that he was able to make significant progress in creating the machines, and manufacturing the goods, that make our standard of living today as much higher than that of our grandfathers as theirs was higher than that which existed 2,000 years ago. You who have chosen farm crops research for your life work have identified yourselves with a group of men and an enterprise that carry large responsibility for promoting the welfare of all mankind.

ALL SCIENCE IS INTER-RELATED

As in other fields of study, it should be obvious that there is no independent science of agronomy. Every known fact or new finding in physics, chemistry, or biology that has any bearing whatsoever on plant growth becomes part of the stock-in-trade of the scientist engaged in crops research. There is only one natural world. All that we have been able to discover about any manifestation of nature has the possibility of supplying much-needed information, or greatly improved tools, with which to carry forward explorations in a dozen other of our academic divisions of science.

Lancelot Hogben has pointed out a striking example of this very great dependence that all fields of science have on new developments entirely outside their own customary borders. The Egyptians, 2,000 years ago, had gone just about as far in several phases of science as was possible until certain new materials were made freely available. Foremost among these was glass. The Egyptians knew how to make glass, but theirs was a colored glass used for jewelry and decorative purposes. In a warm, dry climate, they had no urgent need for window glass in their houses.

When, more than 1,500 years after the Egyptians had been overthrown and most of their culture destroyed, the Mediterranean civilization of the Romans and the Moors penetrated into the cold and wet climate of Northern Europe, there developed urgent need for a transparent material that would permit light, but not cold, to enter men's houses. Then it was that the glassmakers of northern Italy discovered how to produce relatively cheap window glass.

This new transparent material made possible the thermometer and the barometer, which opened up great new vistas for the physicists.

Lenses were cut from the glass, and the astronomers saw for the first time literally hundreds of new worlds. Other lenses were fashioned into microscopes, and man found all around him tiny atoms of life that were responsible for spectacular changes in the composition of foods and other products as well as the cause of scores of diseases of animals and humans. There could hardly be a science of chemistry until glass was available with which to make chemical apparatus. And so I might go on.

It is probable that even if the Egyptians had been allowed to continue their studies uninterrupted, they would not have discovered the value of transparent glass because there is nothing about glass that on casual examination would appeal to an astronomer or a physicist. Further progress in man's scientific knowledge had to wait until, by accident, there developed a popular demand for a relatively simple product, which, when properly fashioned, constitutes one of the most useful materials that has ever been found.

AGRONOMY HAS BENEFITED FROM FINDINGS IN OTHER DIVISIONS OF SCIENCE

All of you are familiar with similar instances where agronomy has benefited by findings made in other divisions of science. Perhaps the most spectacular was the contribution of pure research in genetics made by G. H. Shull and E. M. East on which the nationwide hybrid corn program has been built. George Washington tried to introduce alfalfa into Virginia more than 150 years ago. He failed because fundamental knowledge in the field of soil chemistry and bacteriology was not yet available. Today, alfalfa can be grown in every state of the nation.

It is a paradox that, while there is a oneness about all science, the field in which you men work, farm crops, has very little that it can call solely its own. If one were to allocate all plant disease work to plant pathology, all soils relations to soils, and make similar assignments to genetics and botany, there would be little left that the field of farm crops could claim for itself.

This situation is likely to obtain with any department in applied science. With agronomy it is particularly necessary that we recognize the interdependence of our work with that under way in other departments and divisions. Misunderstandings can be avoided if we welcome the contributions of those engaged in allied fields instead of giving them the impression we think they have invaded our private preserve. I submit the following as my recommendations to those working on farm crops as regards their relationships to other scientists:

1.—*Promoting better relationships between agronomy and other sciences.* Nature did not have academic divisions of science in mind when she created the field crop problems that confront farmers. Research workers will be well advised if they build their projects around a field problem, instead of thinking in terms of what fits nicely inside the defined prerogatives of a particular department.

2.—*Invite fellow scientists to help plan the new projects.*—Facing a

problem that cuts across academic line fences, it is just common horse-sense to invite the men on the other side of the fence to sit with you when you make your plans for attack on the problem. Most of us are so made that we have a lot more enthusiasm for an undertaking we have helped to plan as in contrast with being called in afterwards to assist some other person or group that has already selected the project, determined the goals to be sought, chosen the tasks they will assume, and left to the other fellow little else than doing as he is told, or else open to the charge of being a non-cooperator.

3.—Applied research as worthy as "pure" research.—There is no reason for an agronomist to develop a defensive or inferiority attitude because his research is in an applied field. So-called "pure" or "fundamental" research represents one of the most noble callings of man, and it surely has been a powerfully effective factor in advancing human welfare. But applied research has been, and can be, every bit as worthy, as constructively useful, and as deserving of recognition on the part of both laymen and scientists.

The staff member in one of the basic science departments can study tropical plants as well as those grown on the farms of the state where the university is located. Not so with the agricultural experiment station staff member. He is not free to gather posies in any part of the scientific garden. He must make his plants grow, and flower, and fruit where the farmers of his state want them. Changing the metaphor, the so-called pure scientist can chase any rabbit that crosses his path, but the applied scientist must steadfastly stay with his assigned problem. The truly efficient and worthy scientist in an applied field thus has much the more difficult task.

The worker in "pure" science is deemed successful if he contributes to the world's knowledge, even though the facts he uncovers have absolutely no practical utility. The worker in applied science, on the other hand, devotes his energies to the problems that require solution, if mankind is to have health, happiness, and a sense of personal value. The methods of "pure" and applied science are the same. The sole difference between "pure" and applied scientists is that one looks upon new information as an end in itself, while the other considers his efforts as being successful only in part until the new facts he uncovers are used to promote some aspect of human welfare.

In our institution, we insist that those of us in the agricultural experiment station have as much authority and competence in the domain of pure science as have those in the so-called basic science departments in the other divisions of the university. One of our staff members puts it this way: "Let the station workers pick a practical farm problem of importance in the local region or state, and then dig as deeply as they can in science in order to find the answer and the explanation of the problem." It has been our experience that it often takes as fundamental research to answer practical farm problems as any project a professor can conjure out of his intellectual curiosity or imagination.

Nor should we be satisfied in our applied research with merely empirical and effective answers to farm problems, even when the farmers think the problems have been solved. We must know *why*

the new methods are successful when the old ones were not. Finding the reasons back of the control may give us a running start towards the solution of other problems that have heretofore completely baffled us.

4.—Cooperative research not only desirable, but necessary.—The biggest paradox in agricultural research, and this is particularly true of investigations with farm crops, is that the farm problems on which we work are constantly demanding for their solution closer and closer teamwork between men in the same and in different departments; and simultaneously specialization in science is continually intensifying the already great individual differences between research workers. Cooperation between scientists in the several departments of an experiment station is not a question for debate—it is an absolute necessity.

As in the past, new ideas and new methods of approach in the field of science will likely have a single parent, i.e., they will be conceived in the minds of individual scientists and not come automatically out of conferences in which a considerable number of men join to discuss a particular project. But the very practical fact remains that the effective testing out of the new ideas in the laboratory and the field will require coordinated effort by trained men in different technical fields. The need is for individualistic thinking coupled with cooperative action. Good men and not organization machinery are the productive factors in research, but even the best men in crops research will increase their effectiveness enormously if they can secure the active participation of workers in other divisions who can contribute specialized assistance to the cooperative program.

A very real asset of cooperative research is the help it gives the individual worker in guarding him from drawing too quick conclusions. Many a scientist would have been spared the embarrassment of getting too far out on a limb and having to retreat or permit the limb to be sawed off with him on it if he had had a scientific partner to counsel with him before he rushed into print.

This year we are celebrating the hundreth anniversary of the publication of Liebig's celebrated book on "Organic Chemistry and Its Application to Agriculture and Physiology." I wonder how many of you know that Liebig, one of the most eminent research workers of all time, was a strong believer in cooperative research, and himself practiced it to a marked degree. His partner was another chemist, Wöhler, who was a top-flight scientist in his own name. Writing of the close association over many years between himself and Wöhler, Liebig said,

"While in me the predominating inclination was to seek out the points of resemblance in the behaviour of bodies or their compounds, he possessed an unparalleled faculty of perceiving their differences. Acuteness of observation was combined in him with an artistic dexterity, and an ingeniousness in discovering new means and methods of research or analysis, such as few men possess.

"The achievement of our joint work upon uric acid and oil of bitter almonds has frequently been praised; it was his work. I cannot sufficiently highly estimate the advantage which the association with

Wöhler brought to me in the attainment of my own as well as of our mutual aims, for by that association were united the peculiarities of two schools—the good that was in each became effective by cooperation. Without envy and without jealousy, hand-in-hand, we plodded our way; when the one needed help, the other was ready. Some idea of this relationship will be obtained if I mention that many of our smaller pieces of work which bear our joint names were done by one alone; they were charming little gifts which one presented to the other."

Wöhler, on the other hand, wrote as follows.

"We two, Liebig and I, have dissimilar kinds of talent; each, when in concert, strengthens the other. No one recognizes this more fully than Liebig himself, and no one does me greater justice for my share of our common work than he."

If these two chemists, each as capable of independent achievement as any scientists of their generation, found joint action so productive in the relatively specialized field of organic chemistry, how much more necessary it is today in farm crops research where the contributions from at least three or four branches of science are required for the solution of most problems.

5.—Aids to success in cooperative research.—Accepting the premise that cooperation in research is desirable, is not enough. We need to search for, and to adopt, the procedures which will be most likely to advance cooperative effort in research.

In general, it is best to have the men who are to make a study be the ones to plan the details of the cooperative arrangement. Cooperation is seldom effective or lasting when imposed from above.

Getting the other fellow, or another department, to perform routine tasks like planting, cultivating, and harvesting experimental field plots, making standard chemical analysis of research materials, etc., are dishwashing types of tasks. Scientific workers and subject matter departments should assume responsibility for arranging for the funds or personnel to carry forward the merely routine tasks which are to be done in another department. Cooperative research means just what it says, cooperation in research, not asking another person or department to cut wood and haul water for you.

The democratic method should be followed in which all the interested persons share in deciding policies and procedures. The division of labor should attempt to coincide with the research responsibilities assumed. All cooperating members should have the assurance that their research group will retain authority regarding all technical phases of the project until the results are ready for release under the joint sponsorship of all the cooperating persons.

6.—Special need for cooperation between natural and social Scientists.—I have the personal belief there is special need and large opportunity for more cooperation in research between the natural sciences like agronomy and the social sciences like economics.

We must never forget that our purpose in agricultural research is to protect and to promote the economic well-being of farm people. We are concerned with soils, plants, animals, and machines only as

means to an end. The end is man, his prosperity, his health, and his happiness.

This lays a responsibility on all of us in agricultural research constantly to check our activities to determine if what we are doing is only interesting to us or whether it really offers promise of being socially useful. It is not enough that we learn whether a particular farm practice will improve crop yields qualitatively or quantitatively. It is just as necessary that we know whether the cost of the new practice makes its use profitable. It may even be that we have a national surplus of the crop in question and our need is for effective ways of reducing its production.

We constantly must recognize that we live in an economic order of growing complexity and we are all much more dependent on each other than was true in the past, even as late as 25 years ago. Every significant discovery made in the experiment station is certain to influence the management of thousands of individual farms and the conduct of that branch of agricultural industry which is involved. The station will be most useful to those whom it serves if it has social scientists at work alongside the rest of its staff who can aid farmers in evaluating and using the new findings of science so as to facilitate the inevitable adjustments that are called for within and without the line fences of the farms of the state and nation.

Agronomists may feel that it is up to the social scientists to take the initiative in arranging for the cooperation between natural and social scientists. I do not think so. The economists and sociologists are much newer on the scene than those in the fields of production. They still have some of the feeling that they have to make a place for themselves and to justify their objectives and their procedures. You who belong to a well-established line of work have the unfettered opportunity to invite and to encourage their cooperation with you.

7.—*Agronomists have opportunity for synthesis.*—If I were a member of your group, I think I would consider my largest opportunity for successful research would be the synthesis of information and the methods that can be obtained from the many fields of science that deal with plant growth. By and large, modern science has made marvelous advance in the analysis of natural phenomena. There has been increasing specialization to the point that many a scientist knows more about his narrow speciality than perhaps any one else.

Even in our agricultural extension organization, I believe we have carried this analytical approach forward at the expense of synthesis. The county agents and farmers are visited by specialists who often are little more than salesmen or attorneys for their own particular department or program. The man in the field is well-nigh buried under printed, mimeographed, and spoken material, most of which is not definitely integrated or correlated and some of which is actually contradictory. The farmer is asked to coordinate what the agricultural college has analyzed and specialized but has *not* synthesized.

Agricultural science today, and this is particularly true of crop production, is so complex and the need for synthesis so urgent that the task cannot be left to the chance some one may have the inclina-

tion and time to fit the parts together. This job is so important that it deserves major emphasis by many people. It is a large responsibility and calls for a kind of talent even more rare than that required for analysis. The crops specialist who can do the job successfully not only makes a worthy contribution to the welfare of agriculture, but he has the inner conviction that he and those associated with him have demonstrated once more that it is just as important to know how to put bricks and mortar and lumber together into a new building as it is to make bricks, or manufacture cement, or saw boards out of logs.

Instead of building a fence around the area claimed by agronomy and erecting "no trespassing" signs, it seems to me agronomists are smart who invite all to hoe in their garden who are really willing to work on the problems of plant growth that the farmers have asked the agronomists to solve. I'll stake my reputation as a prophet on the forecast that the agronomists will still find plenty left to do after they have received all the help the workers in the other departments are willing and able to give them.

If the agronomists are going to be successful in this job of synthesis, they will have to do their reading and thinking in more subject matter fields than just what is presented at meetings of agronomists. They will need to maintain an interest, and if possible take part, in the technical developments in the allied basic sciences such as plant pathology, plant physiology, genetics, etc. "Cross-fertilization of ideas" with the "pure" scientists will help agronomists, and I am sure it will benefit the laboratory folks who learn from you the pressing problems of the farm that only science can solve.

SCIENTISTS HAVE LARGE STAKE IN PROTECTION OF DEMOCRATIC PROCEDURE

We live at a time when democracy is on trial as perhaps never before. In most of the world it is frankly on the defensive, if not in retreat. Science and research, as we know them, are products of the free minds of free men. It is doubtful if, under a totalitarian regime, the United States would provide research employment for many of us here today. We have our jobs at stake as well as our liberty and our freedom.

The democratic tradition is of long standing in research. Scientists have always stood for the policy that truth in science can be determined only by direct appeal to nature herself instead of to authority. As Huxley put it, "The man of science has learned to believe in justification, not by faith, but by verification."

The victories of science have come almost always in quiet laboratories where only a few are present and far away from big groups of regimented men. There has been a minimum of organization and formal procedure. No one barked orders and commands. In the truly democratic tradition, each worker has had the maximum of independence commensurate with effective progress by the small group of which he was a member. In all the history of mankind, no other

company of men, and no other system of organization, has been able to do so much to improve the material welfare of humanity.

Research workers have more to fear from regimentation than perhaps any other group in our society. If we are to retain our freedom, we must not only resist vigorously every effort to make us walk or think in lock-step, but we here and now must take every possible action to insure that the democratic method in all our public agencies and programs makes the adjustments necessary to insure the highest efficiency in meeting the problems of the present day. We must also be sure that the rank and file of our fellow citizens join with us in making democracy successful, which I am afraid necessitates a lot more self-sacrifice than most of the "pressure groups" in our present-day economic life have so far exhibited.

Finally, I suggest that those of us engaged in research have much to be grateful for in these times of widespread turmoil and suffering. Science has given mankind a vision of what the world will be like when man's spiritual and moral development catches up with his achievements with material things. Nearly half a century ago, Pasteur put it this way:

"Two opposing laws seem today to be in combat—a law of blood and death which, daily devising new weapons of war, compels the people to be prepared always for the battlefield; and a law of peace, work and welfare, which is concerned only with the delivery of humanity from the scourges which beset it. The one seeks only violent conquests; the other the relief of mankind."

The world expects great things of scientists. The historian can tell us of the past, but he cannot change it. The artist may paint the future as he would like to see it, but he is powerless to bring it to pass. Only the scientist can make his dreams come true. "No one can look into the future," said Kettering, "except through the windows of research laboratories."

Sir Richard Gregory expressed the philosophy of all of us, I believe, when he wrote:

"The pleasure derived from the discovery of some secret of Nature, unknown before except to the Architect of the Universe, surpasses all the rewards the world can give. It is a compensation that takes the place of worldly riches and enables unselfish work to be done from which others often make commercial gain. While men engaged in other pursuits lose their interest in later life, in the man of science the love of nature and the desire for new knowledge is eternal."

Those of you who now enjoy the opportunity to spend your time in research, particularly in a field like farm crops where there are so many opportunities to advance the welfare of all mankind by your findings, are more fortunate than you probably appreciate. I can't see how you can envy any one, least of all an administrator. When Gregor Mendel was made abbot of his monastery, he had the whole institutional garden under his supervision. But his research days were over and there is no record of accomplishments of scientific importance, or even of great personal achievement, after he left his little plat of peas and became the custodian of the monastery.

Yours is a high calling; you have been making extraordinary progress; the world recognizes its debt to you; and I know you see more possibilities of progress ahead than you have already made. I congratulate you and wish you the continued success I am sure you will have.

THE EFFECT OF CYANAMID AND POTASH WHEN PLOWED UNDER WITH ORGANIC REFUSE ON THE YIELD OF CORN AND SUCCEEDING CROPS[1]

Harry L. Cook and George D. Scarseth[2]

As early as 1922, Conner (2)[3] stated, "Except on those soils which still have a large portion of unexhausted nitrogen left, the nitrogen problem is the most important soil fertility problem before the corn belt farmer and the time has arrived when the lack of nitrogen is seriously reducing yields."

During the next decade many experimental studies of this problem were made in Indiana and other states. In Bulletin 386 of the Indiana Station (4) the following summary is made: "The effects of nitrogen applied to corn, either at planting time or as side-dressings later, were quite variable. The results indicate that neither practice is practical for increasing corn yields."

Miles (3), in an analysis of 23 corn fertility experiments in which 261 comparisons of PK with NPK were possible with the nitrogen varying from 2 to 6 pounds per acre, points out that when less than 6 pounds of nitrogen are applied per acre, the nitrogen in the fertilizer resulted in a decrease, on the average, in the yield of corn. Since far too small a proportion of legumes to other crops is grown in Indiana, the nitrogen problem is not becoming any less serious. In fact, it is becoming very apparent that the fertility level of the upland mineral soils is almost a function of the nitrogen content.

In 1937 some preliminary experiments were conducted and in 1938 a project was set up for further study of the nitrogen problem. In considering this from a theoretical standpoint, it was decided that plowing under fairly large quantities of the nitrogen carrier with organic refuse offered the best solution. Since approximately 90 pounds of nitrogen are required to produce 50 bushels of corn, too much should not be expected from small amounts added in the row. Side-dressings have given very unsatisfactory results because of the erratic rainfall in mid-summer.

The plowing under of the nitrogen carrier with organic material places the nitrogen at a depth where the soil is almost always moist. Furthermore, plowing under an ammonia-forming type of nitrogen would prevent its loss because of the fixation of the ammonium ion on the clay particles until such a time as nitrification would occur. This should be delayed by three factors: First, the usual wet condi-

[1]Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Indiana. A portion of a thesis which will be submitted by the senior author to the Graduate School, Purdue University, in partial fulfillment of the requirements for the degree of doctor of philosophy. This work was made possible by a fellowship grant from the American Cyanamid Company. Also presented at the annual meeting of the Soil Science Society of America held in Chicago, Ill., December 4 to 6, 1940. Received for publication December 6, 1940.

[2]Fellow in Agronomy and Soil Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 293.

tion of the soil in the spring would exclude the oxygen necessary for rapid nitrification; second, the cool temperature would be below that necessary for optimum nitrification; and third, the organic matter plowed under with the nitrogen would favor reducing conditions which should delay nitrification until later in the season. During the early part of the season, as the organic matter decomposed, the bacteria would probably combine some of the mineral nitrogen into organic forms. All these factors appear to be highly significant when considering the problem of supplying nitrogen throughout the whole growing season, particularly during the summer when the demands are greatest.

The project reported upon here was started in 1938 for the purpose of studying the value of cyanamid as a source of nitrogen to be turned under with highly carbonaceous crop residues in supplying nitrogen for the corn crop and in building up soil humus as a supply of nitrogen for succeeding crops. Only the data obtained in the field will be reported in this paper. The laboratory and greenhouse data will be considered later.

EXPERIMENTAL

These experiments were designed for the treatments to be applied preceding the corn crop on several of Indiana's major corn soils. The treatments consisted of four rates of cyanamid and three rates of muriate of potash. The cyanamid and muriate of potash were plowed under with various crop residues on square plots containing 100 hills of corn which were fertilized with 300 pounds per acre of 0–16–4 in the row when planted. This analysis was chosen to supply 12 pounds per acre of K_2O, an amount that has been generally recommended for corn in Indiana, and an amount of P_2O_5 (48 pounds per acre) which it was hoped would be sufficient to eliminate phosphorus as a limiting factor in this study. Plant tissue tests indicated that this element was supplied in abundance, except on the Miami silt loam during the 1940 season.

In 1938, the plots were laid out in a block of four replicates, but in 1939 and 1940 the lay-out consisted of five replicates in a modified Latin square. All corn yields given are corrected for stand, where such correction is significant, and reported as bushels per acre of shelled No. 3 corn.

CORN YIELDS

In Table 1 are shown the corn yields produced on six important Indiana soil types by the various combinations of cyanamid and muriate of potash plowed under with organic matter preceding the crop. The data presented are the averages of four or five replicates at each location. No averages between various locations or years have been made since the results of each test must be studied in relation to the environmental complex involved.

CLIMATIC INFLUENCES

Since the weather plays such an important role in the results obtained from any study of this kind, rainfall records were kept for each location. In general, the weather in 1938 was quite favorable for corn. Excessive rain during May delayed planting of corn on the

Crosby and Clermont soils, and a torrential rain on the Crosby soil at the time of emergence so damaged the stand that the results for that soil in 1938 are of little value. The 1939 season was characterized by a very dry spring, a well-distributed abnormally high rainfall during the summer, and a dry fall. The 1940 season, in general, was very wet in the spring with an extremely dry summer and fall. At Bedford no rain fell from July 12 to August 18, during which period temperatures above normal prevailed.

In Table 2 is given the rainfall which occurred at the various locations during the three years of this study. This table should be studied along with Table 1 since many of the apparently erratic results are correlated very closely with the rainfall.

RELATIONSHIP OF NITROGEN AND POTASSIUM—TISSUE TEST

Since it is impractical to discuss all the data presented, one case will be used to illustrate some of the interesting and important information obtained during this study. The data accruing during the 1940 season from plots located on the Clermont silt loam at North Vernon will be used for this example because the response of corn on this soil to nitrogen, undoubtedly the first limiting factor, was markedly affected by the level of potash present. Since 400 pounds per acre of cyanamid proved insufficient on this soil type during the 1939 season, the maximum rate was raised to 600 pounds of cyanamid per acre for the 1940 season.

The yields obtained from the various treatments and the results of the plant tissue tests made on August 6 are given in Table 3. A close study of this table shows the correlation which was obtained between the plant tissue tests made the last of July or the first of August, and the yields of corn. As can be seen from this table, 600 pounds per acre of cynamid gave no increase over 400 pounds per acre because potassium became the limiting factor at that production level. Additional increases were obtained from the 600-pound per acre treatment when sufficient potash was present, as is shown in the second part of the table. Conversely, no increases were obtained from potash alone (compare treatments Nos. 1, 11, and 12) because nitrogen was the first limiting factor, but excellent increases can be attributed to potash where an abundance of nitrogen was present (compare treatments Nos. 4, 9, and 10). It might be stated at this point that this relationship of nutrient balance has been noticed in many of the experiments and shows the futility of trying to study one element when another may be the limiting factor.

Another interesting relationship can be seen in Fig. 1 which shows that each 2 pounds of nitrogen plowed under as cyanamid, when sufficient phosphate and potash were present, produced an increase of almost 1 bushel of corn on this soil. The fact that this curve is almost a straight line would indicate that the maximum of production was not reached. The quality of corn was improved markedly by these treatments. This is partly shown by the percentage of grain to total ear weight. Treatment No. 9 produced 4.5 pounds more grain per 100 pounds of ear corn than treatment No. 11 (Table 3).

TABLE 1.—*Corn yields obtained during the 1938, 1939, and 1940 seasons from applications of cyanamid and potash broadcast and plowed under on six important soil types in Indiana.**

Treatment			Soil type, location, and season								
No.	Cyanamid, lbs. per acre†	Muriate of potash, lbs. per acre†	Bedford silt loam, Bedford, successive crops			Parr silt loam, Talbot			Crosby silt loam		
						Successive crops		1939	Thorntown, successive crops		Lafayette, 1940
			1938	1939	1940	1938	1939		1938	1939	
1	0	0	35.0	38.2	12.9	88.5	59.5	62.1	62.7	92.5	29.5
2	100	0	45.8	58.1	34.2	88.3	66.7	72.5	60.3	102.6	36.3
3	200	0	47.2	57.4	27.7	89.5	67.4	67.2	60.6	108.1	49.4
4	400	0	52.4	61.0	26.7	93.9	72.7	70.6	62.7	107.3	52.8
5	100	100	43.0	56.9	31.6	88.9	68.7	69.6	64.7	112.7	49.4
6	100	200	47.7	52.6	33.4	89.3	67.6	66.0	60.9	99.5	50.1
7	200	100	42.6	57.2	17.7	93.2	68.3	75.9	60.9	111.2	56.2
8	200	200	43.2	55.7	19.6	90.6	72.0	76.1	66.7	107.9	59.3
9	400	100	48.2	62.0	23.2	94.6	74.9	78.8	64.5	115.2	68.1
10	400	200	53.8	66.0	24.0	93.0	74.9	78.1	64.5	113.1	71.8
11	0	100	37.2	39.1	12.7	80.5	57.8	60.5	58.8	92.1	30.8
12	0	200	39.8	38.1	9.9	81.8	57.8	64.0	59.8	92.1	33.8
Significant difference.			4.7	3.3	6.3	7.9	5.3	7.7	6.6	3.8	3.2

*The yields are averages of four or five replicates at each location and are in bushels of No. 3 corn per acre.
†Cyanamid and muriate of potash were applied on the previous crop residue and plowed under. All plots received in addition 300 pounds per acre of 0-16-4 in the row when corn was planted.

Treatment			Soil type, location, and season								
No.	Cyanamid, lbs. per acre†	Muriate of potash, lbs. per acre†	Brookston silt loam, Lafayette		Miami fine sandy loam, Rochester, successive crops		Miami silt loam, Lafayette, 1940	Clermont silt loam, North Vernon		
								Successive crops		1940‡
			1938	1939	1938	1939		1938	1939	
1	0	0	68.7	72.9	110.2	92.8	25.2	50.8	27.5	16.6
2	100	0	73.6	76.3	112.8	98.2	15.5	57.7	37.2	39.5
3	200	0	83.9	80.6	110.6	101.4	29.2	59.0	45.4	51.7
4	400	0	84.5	78.7	109.3	101.7	34.0	58.8	55.5	51.4
5	100	100	73.5	84.8	109.3	96.0	17.5	65.9	36.4	42.1
6	100	200	65.5	82.7	111.3	99.4	17.6	58.5	34.5	43.1
7	200	100	85.1	84.8	111.5	102.4	24.5	65.4	47.6	59.4
8	200	200	83.2	85.3	111.5	99.0	23.7	66.4	46.6	57.2
9	400	100	87.4	88.1	111.5	103.0	33.9	71.3	64.0	73.5
10	400	200	83.7	83.5	111.2	96.1	36.7	65.8	60.1	74.4
11	0	100	70.2	77.5	110.5	93.9	25.2	55.2	26.1	16.5
12	0	200	66.1	77.1	106.7	92.8	24.5	56.3	27.1	16.7
Significant difference............			7.4	4.2	4.0	5.7	3.2	5.7	5.7	5.0

‡The rates of cyanamid applied for the 1940 corn crop on this soil were 200, 400, and 600 pounds per acre, respectively, instead of 100, 200, and 400.

TABLE 2.—*Rainfall in inches occurring at various plot locations in Indiana during the growing seasons of 1938, 1939, and 1940.*

Month	Location and season																
	Bedford			North Vernon			Lafayette			Rochester		Thorntown			Talbot		
	1938	1939	1940*	1938	1939	1940	1938	1939	1940†	1938	1939	1938	1939	1940	1938	1939	1940
April......	1.4	6.6	9.5	0.7	7.7	8.6	3.4	5.8	2.9	3.1	4.3	4.3	5.3	5.1	1.8	6.2	3.3
May......	6.4	1.3	3.9	7.6	2.5	3.6	5.7	0.7	4.0	2.9	1.0	7.1	0.3	5.2	4.8	0.5	4.4
June.......	3.3	6.8	1.2	4.3	8.1	4.2	3.8	5.1	4.2	5.8	4.3	5.6	6.8	3.0	6.2	3.5	2.9
July.......	3.9	2.7	1.5	4.6	4.5	0.8	5.6	8.1	1.6	6.4	2.8	6.4	5.4	0.1	6.2	4.6	0.9
August....	2.5	1.5	3.0	3.6	1.7	1.2	2.7	1.5	3.1	3.6	1.8	3.6	1.4	2.5	3.1	2.0	1.8
September .	1.4	1.1	1.7	1.8	1.7	1.1	3.9	0.5	1.0	3.6	0.2	2.4	0.0	1.3	3.4	0.0	1.9
Total......	18.9	20.0	20.8	22.6	26.2	19.5	25.1	22.7	16.8	25.4	14.4	29.4	19.2	17.2	25.5	16.8	15.2

*No rain July 12 to August 19. Above normal temperatures.
†No rain July 16 to August 18, except on Crosby silt loam which received two good showers not received on Miami silt loam.

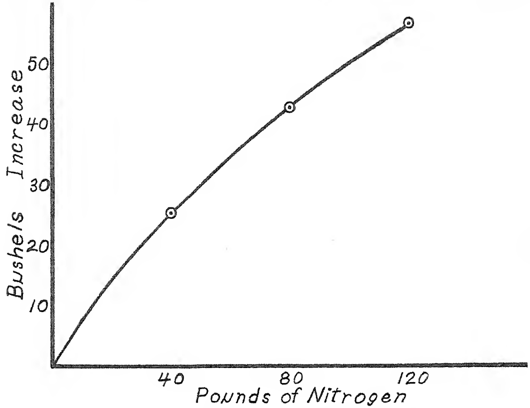

FIG. 1.—Bushels increase of corn produced by 40, 80, and 120 pounds of nitrogen as cyanamid plowed under with organic refuse when adequate phosphate and potash were supplied, 1940 season.

TABLE 3.—*Corn yields in relation to plant tissue tests from cyanamid and potash treatment on Clermont silt loam, 1940 season.**

Treatment			Yields†	Increase over no nitrogen§	Plant tissue tests‖		
No.	Cyanamid, lbs. per acre‡	Muriate of potash, lbs. per acre‡			N	P_2O_5	K_2O
1	0	0	16.6	—	O	H	L
2	200	0	39.5	22.9	O	H	L
3	400	0	51.7	35.1	L	H	L
4	600	0	51.4	34.8	M	H	L-O
11	0	100	16.5	—	O	H	H
5	200	100	42.1	25.6	O	H	M
7	400	100	59.4	42.9	T	H	M
9	600	100	73.5	57.0	T	H	M
12	0	200	16.7	—	O	H	H
6	200	200	43.1	26.4	O	H	H
8	400	200	57.2	40.5	T	H	H
10	600	200	74.4	57.7	O-T	H	H

*Plant tissue tests were made August 6, 1940, and the figures shown are averages of five replicates.

†Bushels per acre of No. 3 corn.

‡Materials were applied to the previous crop residue and plowed under. All plots received 300 pounds per acre of 0-16-4 in the row when corn was planted.

§Significant difference 5.0 bushels.

‖H = High; M = Medium; L = Low; T = Trace.

EFFECT OF FERTILITY LEVEL ON RESPONSE TO NITROGEN

The fact that cyanamid will increase the yield of corn whenever nitrogen is the limiting element is amply illustrated in Table 1, but an interesting example is to be found in the data from the Crosby silt loam for 1939 where 92.1 bushels of corn were produced on the row fertilized plots. When 400 pounds per acre of cyanamid and 100 pounds per acre of muriate of potash were plowed under in addition to the row fertilizer of 300 pounds per acre of 0–16–4, a yield of 115.2 bushels per acre was obtained, an increase of 23.1 bushels. Here, also, the additional potash was necessary to obtain maximum yields.

RESIDUAL EFFECT

On one soil in 1939 and on four in 1940, the residual effect of the cyanamid and muriate of potash which was plowed under for the previous corn crops was measured by the succeeding crops in the rotations. The results obtained are given in Table 4 and indicate that considerable quantities of the nitrogen and potash plowed

TABLE 4.—*Yields of crops succeeding corn for which broadcast applications of cyanamid and potash were plowed under.**

Treatment			Crop, soil type, location, and season				
No.	Cyanamid, lbs. per acre†	Muriate of potash, lbs. per acre†	Soybeans Brooksston silt loam Lafayette, 1939‡	Oats Parr silt loam Talbot, 1940§	Wheat Clermont silt loam North Vernon, 1940‖	Oats Crosby silt loam Thorntown, 1940††	Corn Bedford silt loam Bedford, 1940‡‡
1	0	0	29.2	47.3	11.7	55.0	15.1
2	100	0	29.1	48.4	13.9	72.8	32.5
3	200	0	31.3	56.3	15.1	86.6	32.2
4	400	0	31.7	65.7	17.5	109.8	31.4
5	100	100	32.3	41.6	14.3	67.7	28.8
6	100	200	28.9	38.4	13.7	63.9	30.6
7	200	100	34.3	53.1	16.7	80.5	27.1
8	200	200	32.9	44.5	14.9	69.2	28.0
9	400	100	34.2	97.0	18.5	90.2	29.6
10	400	200	35.6	79.7	17.6	100.3	26.0
11	0	100	34.7	38.4	13.2	51.2	14.7
12	0	200	28.9	37.8	12.0	50.7	12.3
Significant difference.....			5.5	5.3	1.5	7.9	6.0

*The yields are averages of four or five replicates at each location and are in bushels per acre.
†Materials were plowed under for preceding corn crops.
‡Soybeans succeeded the 1938 corn crops on this soil.
§Oats followed the 1939 corn crop on the Parr silt loam.
‖Wheat received 250 pounds per acre of 2–12–6 when seeded and followed the 1938 and 1939 corn crops on this soil.
††Oats succeeded the 1938 and 1939 corn crops on this soil.
‡‡Corn followed the 1938 and 1939 corn crops on Bedford silt loam and received 300 pounds per acre of 0–16–4 in the row at planting time.

under preceding the corn crop remained in the soil for utilization by the crops following the corn in the rotation. This is a very important phase of the study and shows that the usual or natural nitrogen supply of a rotation may well be supplemented by commercial nitrogen whenever the farm practices are such that nitrogen is not adequately provided.

ECONOMIC ASPECTS

The importance of this study from an economic standpoint becomes very apparent when the average corn yields for the last 10-year period in Indiana (36.2 bushels) is considered in the light of the figures put out by the Farm Management Department of this Station which show that the cost of producing an acre of corn in southern Indiana is approximately $15.50 (4). This would require a yield of 31 bushels per acre, with corn at 50 cents a bushel, to defray production costs. In Table 5, which shows the cost of producing corn on variously treated plots on two of southern Indiana's light colored soils, it is to be seen that money must be spent for nitrogen before the above overhead cost can be met. At Bedford it was necessary to spend $2.10 in 1938 and 1939 and at North Vernon $10.80 in 1939 and $15.00 in 1940 in order to cover this overhead. This expenditure is for cyanamid or cyanamid and muriate of potash plowed under in addition to the regular row fertilizer.

Looking at the problem from another angle, $2.10 spent for cyanamid at Bedford returned a profit of $3.35 in 1938, $7.96 in 1939, and $8.52 in 1940. On the Clermont silt loam at North Vernon, Indiana, it was necessary to include potash with the cyanamid for best returns. At this location, $4.50 spent for cyanamid and muriate of potash returned a profit of $3.02 in 1938,$10.80 returned a profit of $7.79 in 1939, and in 1940 $8.40 returned $15.33 profit. Only two of the lower producing soils have been used here as examples; however, since an increase of only 4 to 5 bushels of corn at 50 cents will pay for each 100 pounds of cyanamid, it is not difficult to figure the profit obtained on soils with higher production levels. Even if the increases obtained were only sufficient to pay the cost of application from the standpoint of increasing the soil humus, the plowing under of nitrogen with organic refuse would probably be "money in the bank of soil fertility", particularly since it is a well-known fact that only the portion of the carbonaceous organic matter that can be balanced with nitrogen to provide a favorable carbon-nitrogen relationship can be retained in the soil.

SUMMARY AND CONCLUSIONS

The value of cyanamid as a supplement to the nitrogen supply of the rotation was studied by plowing it under with organic matter preceding a corn crop. The residual effect of this nitrogen was measured by succeeding crops.

It is apparent that the corn crop can utilize fairly efficiently the nitrogen supplied as cyanamid when it is plowed under with organic refuse and that considerable quantities of this nitrogen remain in

TABLE 5.—*Cost of producing corn on Bedford and Clermont silt loams.*

Location and year	Treatment			Yield, bu. per acre	Increase above no nitrogen, bu. per acre	Cost of fertilizer†	Total cost of production per acre‡	Net cost per bu.	Profit per acre§	Cost per bu. increase	Profit per acre from treatments§
	No.	Cyanamid, lbs. per acre*	Muriate of potash, lbs. per acre*								
Clermont, 1938	1	0	0	50.8	—	$ 4.00	$19.50	$ .38	$+ 6.10	—	—
	5	100	100	65.9	15.1	8.50	24.00	.36	+ 9.23	.30	$+ 3.02
	9	400	100	71.3	20.5	14.80	30.30	.42	+ 5.70	.52	− .41
Clermont, 1939	1	0	0	27.5	—	4.00	19.50	.71	− 5.78	—	—
	3	200	0	45.4	17.9	8.20	23.70	.52	− .90	.23	+ 4.83
	4	400	0	55.5	28.0	12.40	27.90	.50	0.00	.30	+ 5.60
	9	400	100	64.6	37.1	14.80	30.30	.47	+ 1.94	.29	+ 7.79
Clermont, 1940	1	0	0	16.6	—	4.00	19.50	1.17	− 11.12	—	—
	2	200	0	39.5	22.9	8.20	23.70	.60	− 3.59	.18	+ 7.33
	3	400	0	51.7	45.1	12.40	27.90	.54	− 2.07	.16	+15.33
	9	600	100	73.5	57.1	19.00	34.50	.46	+ 2.94	.26	+13.70
Bedford, 1938	1	0	0	35.0	—	4.00	19.50	.56	− 2.10	—	—
	2	100	0	45.8	10.8	6.10	21.60	.47	+ 1.83	.19	+ 3.35
	3	200	0	47.2	12.2	8.20	23.70	.50	0.00	.34	+ 1.95
	4	400	0	52.4	17.4	12.40	27.90	.53	− 1.57	.48	+ .35
Bedford, 1939	1	0	0	38.2	—	4.00	19.50	.51	− .38	—	—
	2	100	0	58.1	19.9	6.10	21.60	.37	+ 7.55	.10	+ 7.96
	3	200	0	61.0	22.8	8.20	23.70	.38	+ 7.32	.18	+ 7.30
	9	400	100	66.0	27.8	14.80	30.30	.46	+ 2.64	.39	+ 3.06
Bedford, 1940	1	0	0	12.9	—	4.00	19.50	1.51	− 13.03	—	—
	2	100	0	34.2	21.3	6.10	21.60	.63	− 4.45	.10	+ 8.52
	3	200	0	27.7	14.3	8.20	23.70	.85	− 9.69	.29	+ 2.96
	4	400	0	26.7	13.8	12.40	27.90	1.04	− 14.40	.63	− 1.79

*Materials were applied on the previous crop residues and plowed under. All plots received 300 pounds per acre of 0–16–4 in the row when corn was planted.

†0–16–4, P_2O_5 at 7c per pound, K_2O at 6c per pound, cyanamid at $2.10 per hundred, potash at $2.40 per hundred.

‡This cost includes an overhead charge of $15.50 per acre, a figure obtained by the Farm Management Department covering all growing and harvesting costs, such as, taxes, interest, rent, labor wages of 25c per hour, etc.

§Corn at 50c per bushel with no discount for poor quality. Attention is called to the difference between the two profit columns. The second of these is a differential column and shows profits obtained from use of cyanamid and extra potash.

the soil and can be utilized by succeeding crops in the rotation. While this efficiency was much greater on the lighter colored soils, very significant increases were obtained in almost all cases.

The inter-relationship of the utilization of nitrogen and potassium was noticed in much of the work reported. The need for nitrogen was made more apparent whenever potash was applied and whenever the higher rates of nitrogen failed to provide additional increases, the plant tissue test indicated that potassium had become the limiting element. Whenever there was a deficiency during the last of July or first of August, as determined by the tissue tests, this deficiency was always reflected in the yield.

The importance of climatic influences, especially rainfall, must be recognized in a study of this kind because such factors often make the averaging of data obtained in different seasons misleading, unless a sufficiently large number of years is involved to weigh the data properly.

On the Clermont silt loam in 1939 and 1940, and on the Crosby silt loam in 1940, approximately 1 bushel of corn was obtained for each 2 pounds of nitrogen plowed under as cyanamid when the supplies of phosphorus and potassium were ample. Since this was true at the higher levels of application, apparently the maximum of production was not reached on these soils. It is well understood that this great efficiency would not be maintained indefinitely, since some other element, or the plant's capacity to produce would become a limiting factor. This is probably the case in some of the more fertile soils used in these experiments which gave smaller or no responses.

It is evident from the field results that a considerable amount of the nitrogen from cyanamid persists in the soil in one form or another and is available to the following crops.

Since most rotations contain limited soil-building crops and must be used for a long period at relatively low production levels before the soil organic matter and nitrogen supply are built up, the use of cyanamid on light colored soils to step up the production rapidly to a profitable level and to avoid the expensive delay has practical possibilities. When this profitable level is rapidly attained, the good rotation practices can be followed.

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THE INFLUENCE OF SEASON AND LOCATION ON THE GRAIN OF SEVERAL WHEAT VARIETIES[1]

C. A. Lamb and E. G. Bayfield[2]

TEN varieties of winter wheat were grown each year at 15 locations in Ohio during the four seasons of 1930 to 1933, inclusive. Baldrock was substituted for Berkeley Rock after 2 years and Gladden was omitted in 1930. Studies on these varieties have already been published by Bayfield (1)[3] and by Bayfield and Shiple (2). The present paper is concerned with a more detailed analysis of certain of the data with the object of estimating the influence of variety, season, and location upon yield, weight per bushel, wheat ash, and wheat protein, and the interrelationship of these factors.

The plots were grown at widely distributed points in the Ohio. Locations 1 to 5, inclusive, were close together in Fulton County and on markedly different soil types; all the rest, except location 6 (Henry County), were on silt loam but widely spread over the state. Numbers 1 to 5, inclusive, and number 10 were on private farms; the remainder on farms operated by the state. Location numbers are those used by Bayfield (1). Further details regarding soil type, etc., are also given by him.

The individual plot yield, weight per bushel, and wheat protein figures have been published by Bayfield (1). Wheat ash was determined later and will be presented in a bulletin of the Ohio Agricultural Experiment Station in the near future. This bulletin will report on soft wheat quality studies in Ohio, 1930–1939.

ANALYSIS BY INDIVIDUAL SEASONS

Table 1 gives the mean values of each of the characteristics considered by varieties and also by locations for each year separately. In Table 2 the results of the 16 analyses of variance are presented.

In so far as yield is concerned, differences between varieties are highly significant. For 1930 the F value indicates odds not greatly in excess of 19 : 1, but this low value is obviously due to the large error term. The variance for interaction was large in this particular season because of the very low yields of some varieties at the Miami County farm (location 12). Trumbull gave only 6.3 bushels per acre and Nabob and Red Rock were also definitely below the average. At all other places these three varieties yielded at or above the average. Since differences between varieties were as large in 1930 as in other years, it seems reasonable to conclude that they were equally significant and that the lower F value was due to the low-yielding plots.

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication December 12, 1940.

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[3]Numbers in parentheses refer to "Literature Cited" p. 303.

TABLE 1.—*Means for yield, weight per bushel, wheat ash, and wheat protein by varieties and by locations for individual seasons.*

Variety	Yield per acre, bushels				Weight per bushel, pounds				Wheat ash, %				Wheat protein, %			
	1930	1931	1932	1933	1930	1931	1932	1933	1930	1931	1932	1933	1930	1931	1932	1933
Trumbull	29.5	34.7	27.6	32.7	61.2	58.2	60.2	58.7	1.66	1.75	1.67	1.74	10.5	10.4	11.1	10.9
Nabob	32.2	34.4	28.5	34.4	61.2	58.2	60.5	59.4	1.56	1.65	1.63	1.66	9.6	9.6	10.7	10.1
Fulhio	30.5	34.5	28.4	32.7	61.2	58.1	60.2	58.8	1.65	1.73	1.67	1.76	10.2	10.3	11.1	11.0
Red Rock	29.5	36.5	29.5	27.4	61.2	58.1	60.3	58.9	1.70	1.74	1.69	1.73	10.5	10.2	10.8	10.9
American Banner	26.8	33.8	30.6	28.0	59.3	56.2	58.7	57.9	1.60	1.75	1.63	1.71	9.3	9.6	9.9	10.4
Berkeley Rock	28.0	33.0	—	—	61.5	58.7	—	—	1.70	1.72	—	—	10.4	10.3	—	—
Baldrock	—	—	29.6	27.8	—	—	60.1	59.4	—	—	1.69	1.73	—	—	11.0	11.1
Michigan Amber	28.9	31.7	27.4	27.6	61.2	57.8	59.4	59.0	1.67	1.74	1.71	1.75	10.2	10.5	11.3	10.8
Kharkof	25.8	31.8	27.2	30.6	62.1	58.0	59.9	59.5	1.63	1.73	1.68	1.72	10.1	10.2	10.9	10.8
Fultz	29.3	30.8	25.9	29.4	61.3	57.7	59.9	59.3	1.70	1.77	1.76	1.80	10.0	10.1	10.9	10.7
Gladden	—	35.4	27.7	31.5	—	58.2	59.6	59.3	—	1.68	1.69	1.72	—	9.5	10.6	10.1
Average	28.9	33.7	28.2	30.2	61.1	57.9	59.9	59.0	1.65	1.72	1.68	1.73	10.1	10.1	10.8	10.7
Location:																
1	15.2	13.4	10.9	20.4	61.8	58.9	58.3	58.7	1.75	1.75	1.74	1.60	10.1	8.8	9.6	9.0
2	39.0	22.9	35.2	24.8	59.9	59.4	58.6	59.0	1.56	1.78	1.50	1.65	9.0	9.1	9.1	10.2
3	28.9	—	35.5	22.9	60.6	—	60.5	59.7	1.67	—	1.54	1.70	9.1	—	9.5	11.6
4	41.5	40.7	33.6	30.0	61.2	59.7	58.9	59.5	1.53	1.62	1.69	1.76	10.0	10.1	10.2	12.6
5	—	40.2	28.0	26.7	—	59.2	58.2	59.9	—	1.67	1.69	1.81	—	10.0	9.5	11.4
6	—	34.4	32.3	—	—	59.8	62.3	—	—	1.65	1.59	—	—	9.7	10.1	—
8	22.2	36.0	29.5	—	61.2	60.1	60.4	—	1.63	1.76	1.73	—	9.7	10.0	12.9	—
9	37.2	45.3	25.6	44.8	62.4	57.0	60.3	60.3	1.68	1.70	1.74	1.73	10.4	9.9	12.6	11.2
10	33.6	32.4	28.6	31.8	62.0	58.1	61.1	60.5	1.69	1.68	1.68	1.70	10.7	9.7	10.4	10.2
11	21.8	37.5	19.7	29.9	60.5	55.8	61.0	58.3	1.68	1.77	1.80	1.81	11.4	10.7	12.5	10.7
12	18.5	30.3	39.2	40.6	61.0	54.6	60.0	57.3	1.75	1.83	1.65	1.79	11.1	11.2	12.1	11.1
13	28.7	—	28.7	35.6	61.8	—	59.4	57.2	1.61	—	1.74	1.78	9.1	—	9.6	9.6
14	31.8	39.8	26.5	30.0	60.0	56.4	58.8	58.6	1.59	1.81	1.74	1.73	10.2	12.1	9.9	10.3
15	—	31.1	22.0	25.0	—	56.0	60.3	59.4	—	1.68	1.75	1.72	—	9.6	13.7	10.2
Average	28.9	33.7	28.2	30.2	61.1	57.9	59.9	59.0	1.65	1.72	1.68	1.73	10.1	10.1	10.8	10.7

TABLE 2.—*Analysis of variance by individual seasons.*

Characteristic	Source of variation	1930		1931		1932		1933	
		9 varieties 11 locations		10 varieties 12 locations		10 varieties 14 locations		10 varieties 12 locations	
		Degrees of freedom	Mean square	Degrees of freedom	Mean square	Degrees of freedom	Mean square	Degrees of freedom	Mean square
Yield per acre, bu.	Variety	8	41.01*	9	39.66†	9	26.83†	9	76.90†
	Location	10	675.98†	11	758.09†	13	530.09†	11	519.56†
	Interaction	80	19.67	99	8.25	117	6.65	99	5.70
Weight per bushel, lbs.	Variety	8	6.227†	9	5.388†	9	3.805†	9	2.857†
	Location	10	6.188†	11	35.534†	13	14.538†	11	11.207†
	Interaction	80	0.460	99	0.500	117	0.538	99	0.367
Wheat ash, %	Variety	8	0.0234†	9	0.0149†	9	0.0205†	9	0.0157†
	Location	10	0.0477†	11	0.0458†	13	0.0731†	11	0.0398†
	Interaction	80	0.0016	99	0.0046	117	0.0016	99	0.0022
Wheat protein, %	Variety	8	1.914†	9	1.581†	9	2.126†	9	1.533†
	Location	10	5.872†	11	8.056†	13	23.951†	11	9.361†
	Interaction	80	0.131	99	0.205	117	0.152	99	0.202

*Significant; odds >19:1.
†Highly significant; odds >99:1.

Single plots only were grown for this study in nearly all cases. The laboratory work involved made it impossible to handle duplicate plantings.

Differences in weight per bushel were very clearly influenced by variety and location, as were also wheat ash and wheat protein, which gave highly significant F values.

The average figures are not strictly comparable from year to year because of changes in the variety list and in the locations represented. Discrepancies so introduced are not too serious, however, and in a general way the averages show the differences between seasons. Inter-season comments are reserved till the discussion of the 4-year combined analysis, because in the data presented there, strictly comparable figures are given.

From the analyses it can be seen that relatively small differences have mathematical significance and that even the figures for the 1% level are low, especially for wheat ash. In Table 1 differences of 2.5 to 3.0 bushels per acre in yield, 0.6 to 0.7 pound in weight per bushel, 0.04 to 0.06% in wheat ash, and 0.4 to 0.5% in wheat protein suggest real differences between varieties or between locations. For all pratical purposes these are probably as sensitive measures as are necessary.

Correlations between all the possible pairs of the four characteristics considered have been obtained by the method of covariance. Table 3 gives the r values computed in each of the four seasons separately.

Because the number of varieties and locations is small, r must be large before it has statistical significance, and the experiment cannot give conclusive evidence on relatively weak associations. It seems justifiable, however, to consider whether the relationships which are broadly indicated are reasonable.

The correlation coefficients for *yield* with *weight per bushel* suggest small or unimportant relationships. Varieties and locations differed in yielding abilities and gave different weights per bushel, but the high yields were not consistently associated with either high or low test weights.

Correlations for *yield* with *wheat ash* varied greatly from season to season, not only in total, but between varieties and between locations as well. The relationship would appear to be essentially negative, although there was one coefficient in 1933 of considerable positive magnitude. In 1930, and again in 1932, location means gave a high r value; in the other years they did not. Varieties gave a high value in 1932 but very low in 1930. Apparently behavior is governed largely by the specific climatic conditions prevailing at any one place in any one season, and this result is not surprising when the physiological processes involved in the growth of the wheat plant are considered.

The absolute ash content of the grain is determined by absorption of ash constituents from the soil and the translocation of these elements into the developing kernel. The total weight of the grain, however, is largely made up of products of photo-synthesis and may or may not be more or less independent of the ash fraction. Conditions may readily be defined under which almost any relationship

might exist between yield and ash content. It is not surprising, therefore, that the correlations are somewhat erratic.

TABLE 3.—*Correlation coefficients from covariance for individual seasons.*

Correlation between	Correlation analysis for	Value of r*			
		1930	1931	1932	1933
Yield and weight per bushel	Total	+0.038	−0.081	+0.129	−0.062
	Variety	+0.117	+0.152	−0.231	+0.241
	Location	−0.077	−0.116	+0.161	−0.156
	Interaction	+0.322	+0.070	+0.137	+0.199
Yield and wheat ash	Total	−0.574	−0.266	−0.616	+0.259
	Variety	−0.129	−0.430	−0.654	−0.335
	Location	−0.748	−0.296	−0.682	+0.476
	Interaction	−0.280	−0.260	−0.282	−0.109
Yield and wheat protein	Total	−0.277	+0.371	−0.172	+0.134
	Variety	+0.075	−0.265	0.514	−0.358
	Location	−0.327	+0.528	0.166	+0.220
	Interaction	−0.284	−0.257	0.054	0.030
Weight per bushel and wheat ash	Total	+0.255	−0.373	−0.051	−0.178
	Variety	+0.303	−0.362	+0.080	0.044
	Location	+0.393	−0.500	−0.051	−0.266
	Interaction	−0.141	−0.146	0.150	−0.043
Weight per bushel and wheat protein	Total	+0.253	−0.424	+0.374	+0.252
	Variety	+0.636	+0.351	+0.576	+0.011
	Location	+0.162	−0.576	+0.429	+0.342
	Interaction	+0.053	−0.191	−0.029	+0.055
Wheat ash and wheat protein	Total	+0.526	+0.425	+0.501	+0.458
	Variety	+0.751	+0.617	+0.477	+0.537
	Location	+0.531	+0.466	+0.520	+0.506
	Interaction	+0.187	+0.318	+0.495	+0.305

*Single values of r for variety not statistically significant below approximately 0.7; for location below approximately 0.6.

The correlation between *yield* and *wheat protein*, like that between yield and wheat ash, is somewhat irregular, and is to be similarly explained. The absolute amount of protein in the grain from a plot depends on the amount of nitrogen taken up and the proportion translocated into the kernel, and in considerable degree may be independent of the photosynthetic activity. Since poor soils are represented in the series and since on them the total available nitrogen is low, low yield and low protein may readily be associated in some seasons. On the very rich soils, protein may be high in spite of high yields. Thus, depending upon season, there may or may not be a good correlation between yield and protein content. The analyses indicate

that in some seasons, such as 1932, inherent differences between varieties may be detectable, but such a conclusion is by no means certain.

Weight per bushel and *wheat ash* gave erratic coefficients which might be reasonably expected for reasons already discussed. Much better r values might have been anticipated if the plots had been grown on less widely divergent soil types. There is no reason to suspect that varieties influenced the correlation.

Correlation of *weight per bushel* and *wheat protein* shows considerable differences between seasons but gives several r values that suggest definite association. In 1930 and 1932 the high-protein varieties gave the high weights per bushel. This result was expected, since the hard wheats normally give better test weights than the soft. In 1933, however, the protein values did not follow the usual distribution among varieties and the correlation virtually disappeared.

The high negative coefficient for location in 1931 was obtained in the season of lowest test weights associated with highest yields. Examination suggested that yield might be the disturbing factor, so the partial coefficient with yield held constant was determined. R was +0.139 and lends strong support to the assumption. That yield must be considered an important element affecting this particular correlation follows from the previous discussion.

The correlation between *wheat ash* and *wheat protein* gave consistent positive correlation regardless of how the data were grouped. It has been pointed out that both these characteristics depend upon material absorbed from the soil, mineral elements and nitrogen. Apparently there is a definite relationship here independent of whether photosynthesis is active or not. If ash is high, so is protein, and *vice versa*.

In comparing results it must be kept in mind that both locations and varieties change from season to season. The changes are not radical, however, and the conclusion is inescapable that differences of any considerable magnitude are almost certainly not independent of season.

COMBINED ANALYSES

At eight of the locations, eight varieties were grown all four seasons. This group was analyzed separately as a unit, permitting some estimate of the effect of season and of the three simple interactions.

Table 4 gives the mean values by locations, by seasons, and by varieties for the four characteristics being studied and permits examination of the actual values whose differences are tested in the analyses of variance. Data from these analyses are presented in Table 5.

The simple variety, season, and location variances are all highly significant. For yields, where an interaction between variety and season was evident in comparing individual seasons, it was not large enough to interfere with differentiating between varieties. Season was a much more potent factor causing change in rank of varieties than was location, in spite of the very wide range of soils at the locations used. This is in agreement with the findings of Lamb and

TABLE 4.—*Means for yield, weight per bushel, wheat ash, and wheat protein used in the combined study, by years, by variety, and by location.*

	Average of all locations									Average of all varieties							
	Trumbull	Nabob	Fulhio	Red Rock	American Banner	Michigan Amber	Kharkof	Fultz	Grand average	Location 1	Location 2	Location 4	Location 9	Location 10	Location 11	Location 12	Location 14
1930																	
Yield	30.3	32.4	31.0	30.0	28.7	30.2	26.4	30.0	29.9	15.2	39.3	41.3	37.2	34.6	22.4	17.6	31.3
Test wt.	61.1	61.2	61.2	61.2	59.3	61.3	62.0	61.2	61.1	61.8	59.9	61.1	62.3	62.0	60.7	61.0	59.7
Ash	1.66	1.57	1.65	1.72	1.60	1.69	1.64	1.71	1.65	1.75	1.56	1.53	1.67	1.70	1.67	1.75	1.59
Protein	10.8	9.8	10.5	10.8	9.5	10.5	10.4	10.3	10.3	10.1	9.0	10.0	10.3	10.7	11.3	11.1	10.1
1931																	
Yield	34.0	32.8	33.6	35.7	33.9	30.4	31.2	29.6	32.6	12.6	23.3	40.6	45.5	32.8	37.2	30.4	38.8
Test wt.	57.8	57.9	57.5	57.7	55.7	57.3	57.9	57.2	57.4	58.9	59.3	59.6	56.8	58.0	56.0	54.5	56.1
Ash	1.77	1.67	1.75	1.76	1.78	1.75	1.74	1.78	1.75	1.76	1.79	1.64	1.71	1.69	1.77	1.85	1.81
Protein	10.6	9.7	10.6	10.5	9.6	10.6	10.3	10.3	10.3	8.9	9.2	10.2	9.9	9.8	10.8	11.0	12.2
1932																	
Yield	27.1	28.8	28.0	28.6	29.6	26.2	26.4	25.1	27.5	11.2	35.8	32.9	25.2	28.6	19.9	39.7	26.6
Test wt.	60.1	60.2	60.1	60.1	58.3	59.2	59.6	59.6	59.7	58.5	58.8	58.9	60.3	61.2	61.0	59.8	58.8
Ash	1.66	1.64	1.67	1.71	1.64	1.72	1.69	1.78	1.69	1.75	1.49	1.69	1.74	1.68	1.79	1.65	1.73
Protein	11.2	10.6	11.0	10.7	9.9	11.3	10.9	10.8	10.8	9.6	9.2	10.2	12.5	10.4	12.5	12.1	9.9
1933																	
Yield	33.9	36.4	34.0	28.7	29.3	28.1	31.6	30.5	31.6	20.4	25.3	30.5	44.6	31.8	30.0	40.3	29.7
Test wt.	58.7	59.5	58.8	58.9	57.8	58.9	59.6	59.1	58.9	58.5	59.0	59.5	60.2	60.4	58.2	57.2	58.5
Ash	1.73	1.67	1.75	1.71	1.70	1.73	1.72	1.80	1.73	1.61	1.66	1.76	1.73	1.72	1.79	1.80	1.75
Protein	10.8	10.1	11.1	10.8	10.3	10.9	10.9	10.7	10.7	9.0	10.3	12.5	11.2	10.3	10.8	11.1	10.3
All Years																	
Yield	31.3	32.6	31.7	30.8	30.4	28.7	28.9	28.8	30.39	14.8	30.9	36.3	38.1	32.0	27.3	32.0	31.6
Test wt.	59.4	59.7	59.4	59.5	57.8	59.2	59.8	59.3	59.25	59.4	59.2	59.8	59.9	60.4	59.0	58.1	58.3
Ash	1.70	1.64	1.70	1.72	1.68	1.72	1.70	1.77	1.704	1.71	1.62	1.65	1.71	1.69	1.76	1.76	1.72
Protein	10.9	10.0	10.8	10.7	9.8	10.8	10.6	10.5	10.52	9.4	9.5	10.7	11.0	10.3	11.3	11.3	10.6

Salter (3), who reported on the response of wheat to fertility levels. They found the variety-season interaction very highly significant, the variety-level interaction of a much lower degree of significance. The variety-season interaction was significantly greater than that of variety with fertility level. In the present study, comparing the two interactions, variety-season and variety-location, the F value exceeds the 5% point, but not by a great deal. Both experiments support the hypothesis that season is a more important factor disturbing the rank of varieties than is location or fertility level. For the characteristics other than yield this does not hold.

TABLE 5.—*Analyses of variance, eight varieties, eight locations, in four seasons.*

Characteristic		Yield per acre, bu.	Weight per bu., lbs.	Wheat Ash, %	Wheat Protein, %
Source of variation	Degrees of freedom	Mean square	Mean square	Mean square	Mean square
Variety	7	69.31†	12.56†	0.0471†	4.75†
Season	3	325.91†	151.23†	0.1189†	4.48†
Location	7	1614.15†	19.76†	0.0688†	18.21†
Interactions:					
Variety—season	21	26.69†	0.72	0.0055*	0.23
Variety—location	49	13.76	0.80*	0.0042	0.20
Season—location	21	413.90†	10.84†	0.0421†	5.76†
Remainder	147	11.05	0.49	0.0031	0.17

*Significant; odds >19:1.
†Highly significant; odds >99:1.

For weight per bushel, the variety-location interaction is barely significant. For wheat ash, the variety-season variance is a little above the 5% level. For wheat protein, neither of these interactions is significant. Variety rank in weight per bushel, wheat protein, or wheat ash is not seriously disturbed by location or season. Such a situation facilitates the determination of these characteristics of new strains.

Coefficients of correlation from the covariance analysis are given in Table 6. Again, the r values must be large to be mathematically significant, and only a rough estimate can be made as to what factors are probably disturbing the total correlations.

Except in the correlations of wheat protein with weight per bushel and with wheat ash, season gave the largest r values. Variety is an important factor in these two exceptions and also gave large values for yield with wheat ash. Location gave the largest single value in the correlation of wheat protein and wheat ash.

The total correlations were all small except for wheat ash with wheat protein. Apparently season is not a factor here. With the single exception of season, which gave an r value essentially zero, all coefficients obtained were positive, indicating, as pointed out before, that these two factors are influenced in the same general direction by the variety and location differences encountered in this particular setup.

TABLE 6.—*Analysis of covariance, eight varieties, eight locations, in four seasons.*

Correlation between	Correlation analysis for	Value of r*	Correlation between	Correlation analysis for	Value of r*
Yield and weight per bushel	Total	−0.129	Weight per bushel and wheat ash	Total	−0.272
	Variety	+0.116		Variety	+0.040
	Season	−0.649		Season	−0.981
	Location	+0.133		Location	−0.468
	Variety—season	−0.047		Variety—season	−0.080
	Variety—location	+0.262		Variety—location	−0.129
	Season—location	−0.364		Season—location	+0.188
	Remainder	+0.198		Remainder	−0.144
Yield and wheat ash	Total	−0.269	Weight per bushel and wheat protein	Total	+0.074
	Variety	−0.677		Variety	+0.571
	Season	+0.710		Season	+0.187
	Location	−0.223		Location	−0.307
	Variety—season	+0.336		Variety—season	−0.013
	Variety—location	−0.342		Variety—location	−0.035
	Season—location	−0.567		Season—location	+0.245
	Remainder	−0.282		Remainder	−0.031
Yield and wheat protein	Total	+0.074	Wheat ash and wheat protein	Total	+0.427
	Variety	−0.236		Variety	+0.540
	Season	−0.635		Season	−0.127
	Location	+0.533		Location	+0.643
	Variety—season	−0.187		Variety—season	+0.365
	Variety—location	−0.012		Variety—location	+0.355
	Season—location	−0.260		Season—location	+0.429
	Remainder	−0.250		Remainder	+0.414

*Single values for r not statistically significant for varieties or locations below approximately 0.7; for V–S and S–L interactions, below approximately 0.45; for V–L interaction, below approximately 0.3.

The large effect of season on the correlation between weight per bushel and wheat ash is probably in some degree accidental. Seasonal differences in test weight were very large, and it seems reasonable to assume that plump kernels indicate satisfactory photosynthesis and, therefore, a high ratio of carbohydrates in the kernels, which, in turn, is associated with low ash.

The coefficients considered as a whole indicate that correlation studies can be expected to give results which will not necessarily apply when the conditions under which wheat is grown differ much from those of the particular study used. They further suggest a reason for different investigators' obtaining apparently contradictory results.

DISCUSSION

The study throws some light on the advisability of using composite samples for the evaluation of new strains or varieties. By compositing grain from several locations, the power to measure differences between locations is lost, and the effect of location on anything being studied cannot be estimated. The question then resolves itself to

whether or not these effects can be disregarded without leading to unjustified conclusions. By considering the 4-year combined analysis, it is seen that the variety-location interaction, which gives a measure of the differential response of varieties to locations, is in no case of either considerable size or great mathematical significance. The greatest effect was on yield, which is obtained by locations in any case. This study indicates that serious errors would not be introduced by using composites to rank varieties for weight per bushel, wheat ash, or wheat protein, at least if samples were not drawn from a more diverse set of environmental growing conditions. It must be remembered, however, that the varieties included in this series were all of relatively good quality and of proved adaptability to a much larger area than that covered in this study.

From the point of view of the plant breeder or cereal chemist, it seems justifiable to conclude that when strains are tested for several seasons over a range of soil types representative of the area where a new variety is to be recommended, differences in yielding capacity, weight per bushel, wheat ash, and wheat protein can be measured. The differences need not be very large to be significant. In spite of a considerable variety-season interaction for yield, superior sorts should be distinguished without too much difficulty. In the present study, 4-year averages were clearly significant in spite of marked change in rank between seasons. The standard deviations for a single plot, calculated from the triple interaction, were 3.32 bushels per acre, 0.70 pound per bushel, 0.056% ash, and 0.41% protein.

The grower can feel assured that when new varieties are released after several years of intensive testing at representative points in the area considered, their properties have been determined with considerable accuracy and the chances are slight that an undesirable sort will be recommended. The length of time necessary to reach a conclusion will be greater if some seasons vary considerably from normal. This statement assumes, of course, study of more than purely agronomic characteristics.

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A COMPARISON OF DIFFERENT CROPS FOR GRASS SILAGE BY THE USE OF MASON JARS AS MINIATURE SILOS[1]

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THE practice of using hay crops for silage has been given a tremendous impetus in recent years through the discovery of reliable methods for ensiling forage crops. There are many obvious advantages for this method in regions where rainy weather often interferes greatly with haying operations.

In a relatively new practice such as this there are always many questions arising as to methods, procedure, and crops suitable to any particular locality. Among the questions asked by dairymen adopting the practice are, What crops are suitable? At what stage of maturity should they be harvested for silage? How much and what kind of preservative is best adapted? It seemed desirable to undertake studies at the Rhode Island Agricultural Experiment Station that would help answer some of these questions for our conditions.

The first problem that arose was what procedure could be adapted for experimental work that would permit the use of the small field plots that were available for growing the crops and still obtain reliable data on the adaptability of these crops for silage purposes. Large silos and feeding trials with the silage were impossible. This paper will deal largely with studies in procedure.

Silage studies with corn have been conducted at other stations by the use of miniature silos consisting of mason jars, milk bottles, or other small containers. It was decided to try 2-quart mason jars for these grass silage studies. In experiments at the West Virginia Experiment Station (5)[3] mason jars were found to be well suited for use as miniature silos in studies on corn silage.

In 1938 and 1939 chemical analyses were made on the composition of several commonly used hay crops when handled as hay, placed in a large silo, in a small 12-inch tile silo, and in mason jars. The green material as harvested was also analyzed. The sample for the large silo was put through a hand cutter and placed in a bag which was buried in the farm silo as this was being filled. The tile silo was filled at the same time with similarly cut material, packed well, and a weighted wooden follower placed on top. The mason jars were also filled at the same time and sealed with a regular jar rubber and cover. The silage samples were all prepared for analysis at the time the sample bag was reached in the feeding operations.

A sample of the green material was taken as harvested and prepared for chemical analysis. Likewise, the sample to be handled as hay was prepared for analysis as soon as it had cured sufficiently in an open shed to make a satisfactory hay.

The results of the chemical analyses made in 1938 and 1939 are presented in Table 1.

[1]Contribution No. 580 of the Rhode Island Agricultural Experiment Station, Kingston, R. I. Received for publication December 13, 1940.

[2]Agronomist, Assistant Agronomist, and Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 312.

Both the timothy and the grass-legume mixture which were packed in the mason jars made silage which, to all external appearances, was of excellent quality. When packed tightly into mason jars in this way it was found that a consistency similar to silage from a larger silo could be attained. The weight per cubic foot ranged from about 33 to 36 pounds on the average. This compares favorably with weights of silage as taken from ordinary farm silos. Hunter and Bushnell (7) found that silage made from different crops and preserved in sealed quart milk bottles was similar in all respects to silage from large silos.

An examination of Table 1 shows that the conventional proximate analyses of silage made in a mason jar and that from a large silo were very similar throughout. It is recognized, however that this is not a complete measure of quality, for it neglects possible changes in vitamins, acidity, palatability, and other factors.

The chemical composition of the oven-dry material for any crop was also very similar whether the analyses were made on the green material as harvested, after drying for hay, or when preserved as silage. The greatest variation from the general average was found in the tile silo. This was due to some spoilage occurring in these silos. The covers used proved unsatisfactory in this case. There was a tendency for these covers to get wedged against the sides which prevented a good seal.

From these results and results obtained with miniature silos in experimental work at other stations, it was felt that mason jars had proved satisfactory for use in making grass silage for experimental purposes. Certainly the results are near enough to those obtained in larger silos to warrant their use in preliminary determinations of the adaptability of various crops for silage purposes, as well as similar comparisons on other grass silage problems. After such preliminary comparisons it may be desirable to conduct more exhaustive studies by the use of larger silos and feeding trials.

COMPARISON OF MOLASSES AND PHOSPHORIC ACID

A number of materials have been used as preservatives in making grass silage. The most widely used are molasses and phosphoric acid. Woodward and Shepherd (10), in experiments at Beltsville, Maryland, found that using molasses as preservative made grass silage more palatable but did not preserve the carotene or dry matter quite as effectively as did acids. These authors also found that if grasses and legumes are cut at the right stage, the moisture content is satisfactory and if the silo is properly packed, good silage can be made from these crops with very little preservative added.

Bender (3) at the New Jersey Experiment Station reported that grass silage was superior to corn silage in its ability to produce milk of a high color and flavor.

Hegsted and co-workers (6) at the Wisconsin Experiment Station found that alfalfa silage made by the A. I. V. method tended to preserve the protein and carotene better than when molasses was used. However, the differences were not large and the authors conclude

TABLE 1.—*Composition of certain forage crops preserved as hay and as silage.*

Crop	Method of preservation*	Actual composition		Composition on oven-dry basis				
		Moisture, %	Protein, %	Protein, %	Fat, %	Crude fiber, %	Ash, %	N-free extract, %
				1938				
Timothy	Green	75.5	2.19	8.94	—	33.22	—	—
	Hay	11.3	7.49	8.44	—	33.91	—	—
	Silage, mason jar	76.6	1.92	8.22	—	32.55	—	—
	Silage, large silo	73.2	2.23	8.31	—	30.04	—	—
	Silage, tile silo	82.4	1.65	9.38	—	35.37	—	—
Grass-legume mixture	Green	77.8	3.09	13.94	—	31.37	—	—
	Hay	10.0	10.97	12.19	—	35.90	—	—
	Silage, mason jar	79.0	2.55	12.13	—	33.79	—	—
	Silage, large silo	77.7	2.69	12.07	—	33.90	—	—
	Silage, tile silo	81.8	1.98	10.87	—	36.26	—	—

		1939						
Timothy	Green	62.0	3.66	9.63	3.06	32.13	5.99	49.19
	Hay	11.3	7.62	8.59	2.86	33.84	5.74	48.97
	Silage, mason jar	66.03	3.38	9.95	3.88	33.54	6.14	46.49
	Silage, large silo	63.88	3.74	10.36	3.57	33.79	6.66	45.62
	Silage, tile silo	67.39	3.31	10.16	3.07	30.36	6.70	49.71
Grass-legume mixture	Green	70.0	3.65	12.16	2.27	32.21	6.34	47.02
	Hay	10.3	11.67	12.99	2.31	31.60	6.73	46.37
	Silage, mason jar	71.4	3.57	12.51	2.95	30.68	5.65	48.21
	Silage, large silo	62.5	4.96	13.26	3.26	31.86	7.86	43.76
	Silage, tile silo	71.9	3.80	13.51	3.10	29.71	7.39	46.29
Alfalfa	Green	74.3	4.83	18.75	2.22	27.91	7.84	43.28
	Hay	9.6	17.28	19.12	2.05	31.33	7.14	40.36
	Silage, mason jar	72.8	4.42	16.24	3.16	27.86	7.26	45.48
	Silage, large silo	72.1	4.16	14.95	3.68	27.73	9.66	43.98
	Silage, tile silo	77.2	3.57	15.67	3.68	30.23	8.61	41.81
Millet	Green	75.0	1.54	6.18	1.64	29.98	7.90	53.30
	Hay	13.5	6.50	7.51	1.55	33.69	7.92	49.33
	Silage, mason jar	74.9	2.11	8.40	3.04	29.81	8.94	49.81
	Silage, large silo	77.4	1.83	8.12	2.28	32.91	8.39	48.30
	Silage, tile silo	76.2	1.54	6.50	2.32	32.35	8.42	50.41

*Molasses used as preservative at the rate of 60 pounds (3%) per ton for timothy and millet and 80 pounds (4%) for alfalfa and grass-legume mixtures.

that both methods are satisfactory. Conditions of farm practice probably make molasses silage more suitable for general use.

In this experiment various amounts of molasses and 75% phosphoric acid were used with different crops preserved in mason jar silos. The results of chemical analysis of the resulting silage are shown in Table 2.

TABLE 2.—*Composition of grass silage preserved with various amounts of molasses or phosphoric acid, 1939.*

Preservative		Actual composition		Composition on oven-dry basis				
Material	Amount, %	Moisture, %	Protein, %	Protein, %	Fat, %	Crude fiber, %	Ash, %	N-free extract, %
				Alfalfa				
Molasses.......	2	73.0	4.73	17.55	3.61	29.49	5.81	43.54
Molasses.......	3	73.7	4.63	17.61	3.63	21.43	7.23	44.10
Molasses.......	4	72.2	4.93	17.76	3.46	27.36	7.34	44.08
Phosphoric acid	½	77.8	4.36	19.60	3.84	26.98	9.35	40.23
Phosphoric acid	1	76.4	4.31	18.28	3.73	26.64	10.88	40.67
Phosphoric acid	2	76.5	4.31	18.30	3.24	26.64	12.81	39.01
				Sudan Grass				
Molasses.......	2	81.0	1.62	8.55	3.06	31.23	7.55	49.61
Molasses.......	3	80.6	1.69	8.71	2.58	30.35	6.34	52.02
Molasses.......	4	79.9	1.65	8.22	2.75	29.96	6.78	52.29
Phosphoric acid	½	81.3	1.54	8.22	2.60	33.53	6.04	49.61
Phosphoric acid	1	80.2	1.68	8.52	2.69	32.62	7.48	48.69
Phosphoric acid	2	78.0	1.75	7.98	2.99	30.13	10.51	48.39
				Timothy				
Molasses.......	2	68.9	2.14	6.88	2.91	38.39	4.73	47.09
Molasses.......	3	67.7	2.30	7.12	2.87	36.94	4.38	48.69
Molasses.......	4	69.0	2.25	7.25	3.29	36.91	6.77	45.78
				Millet				
Molasses.......	2	87.0	1.51	11.66	3.11	29.14	12.58	43.51
Molasses.......	3	85.5	1.61	11.13	3.06	29.34	11.37	45.10
Molasses.......	4	86.9	1.48	11.10	2.45	29.18	12.55	44.72

From general observations the silage from all treatments was of good quality. The chemical analyses also show little variation among the different treatments for any one of the crops used. The right moisture content of the material to be ensiled seems to be more important than the amount of preservative used. If the material is in the proper condition, only small amounts of either molasses or phosphoric acid are needed as a preservative. No detrimental effects were observed when amounts of either preservative were used in excess of the requirements. Under farm conditions where it is more difficult to control the moisture content of material being ensiled, it is doubtless a good practice to use a little extra amount of preservative in order

to be more certain of having enough. The extra amounts of molasses used have feeding value, while extra phosphoric acid gives that much additional fertilizer value to the manure produced.

In deciding which of these materials to use, several factors need to be considered. Among these are the relative cost of the materials, facilities for using, and the kind of material to be ensiled. In other tests it has generally been reported that molasses adds somewhat to the palatability of the silage produced. The molasses, on the other hand, does not preserve the carotene of the silage as well as does the acid. Whether either of these considerations would be of significance will depend on local conditions.

At the present time the cash outlay will be somewhat larger for the acid treatment. Some of this extra cost, however, is recovered through the added value of the manure. When all things are considered, the actual difference in cost of preservative materials would not be very great.

The facilities for obtaining the preservatives and the ease of handling may be the most important factors in making a choice. This will again depend on local conditions and equipment available.

STAGE OF MATURITY AND COMPOSITION

The chemical composition of forage crops varies considerably with the stage of maturity. Early cut hay usually has a higher protein content than late cut hay. Presumably the stage at which a forage crop is harvested will have a decided influence on the chemical composition of the silage made from it. It is necessary to know whether satisfactory silage can be made from these forage crops at all stages of maturity at which it might seem desirable from the agronomic and feeding standpoints to harvest them.

Woodward (10) concluded that immature grasses made a more palatable silage than mature grasses. A committee appointed by a feed conference and with Professor Bender of New Jersey as chairman (1) made a survey of practices used by dairymen in the northeastern states in making grass silage. A majority of those expressing an opinion on the best stage of maturity of crops for grass silage suggested that grasses and legumes should be cut early. Archibald and Parsons (2) used grasses, legumes, and cereals for making silage. These crops could all be successfully ensiled if cut at the proper stage of maturity. Feeding trials showed that the grass silage was equal to corn silage and superior to dry hay for milk production. Directions for making grass silage with molasses and with phosphoric acid are given.

Several crops, including alfalfa and timothy, were harvested at different stages of maturity in these experiments. The results of the chemical analyses are shown in Table 3.

Satisfactory silage was produced from all crops used at all stages of maturity. In general, the protein content decreased with increase in maturity. In some cases this does not appear to be the case when the figures in the table are examined. Unfortunately, it was not always possible in these preliminary studies to obtain samples from

different stages of maturity from the same plat. The kind of fertilizer used has a very decided influence on the composition of the resulting crop. In several instances where the material was obtained from plats differently fertilized, the type of fertilizer used had as much or more effect on the chemical composition of the crop as did the stage of maturity at which it was harvested.

TABLE 3.—*Composition of grass silage when crops were harvested at different stages of growth.*

Crop*	Stage of maturity	Actual composition		Composition on oven-dry basis				
		Moisture, %	Protein, %	Protein, %	Fat, %	Crude fiber, %	Ash, %	N-free extract, %
				1938				
Alfalfa	Full bloom	77.4	4.29	19.00	3.02	28.42	9.59	39.97
	Late bloom	74.4	4.08	15.92	2.98	34.46	7.08	39.56
Timothy	Full bloom	64.8	2.38	6.75	2.60	37.88	5.27	47.50
	Late bloom	64.0	2.28	6.32	2.59	35.06	2.37	53.66
Red clover	Early bloom	79.4	3.31	16.08	3.16	26.19	5.65	48.92
	Late bloom	78.4	2.68	12.43	3.07	25.52	5.59	53.39
				1939				
Alfalfa	Early bloom	72.3	4.61	16.63	3.71	30.49	6.52	42.65
	Late bloom	73.0	4.73	17.55	3.61	29.49	5.81	43.54
Timothy	Early bloom	68.9	2.14	6.88	2.91	38.39	4.73	47.09
	Late bloom	65.8	2.89	8.43	2.59	39.17	3.29	46.52
Millet	Heading	85.5	1.61	11.13	3.06	29.34	11.37	45.10
	Late bloom	74.9	2.11	8.40	3.04	29.81	8.94	49.81

*Molasses used as preservative at 3% rate for timothy and millet and at 4% rate for clover and alfalfa.

COMPARISON OF DIFFERENT CROPS FOR GRASS SILAGE

In any given region certain crops have proved themselves reliable forage producers. Some may have become established as more or less permanent hay or pasture crops while others are adapted for temporary hay or pasture. Information is needed on the adaptability of these crops for making grass silage.

In the survey of practices with grass silage in the northeastern states it was found (1) that crops ensiled included alfalfa, clover, soybeans, clover and timothy, cereals, oats and peas, soybeans and sudan, and various other mixtures. Apparently, all were ensiled satisfactorily. Ragsdale and Herman (9) state that, "Any crop that can be utilized as dry hay or roughage can be made into silage." Camburn and co-workers (4) report that grasses and legumes can be successfully ensiled either with or without molasses provided their dry matter contents range between 30 and 40%. They state that it is

advisable under farm conditions to add either molasses or acid because it is difficult to control the dry matter content of the ensiled crops closely. It is recommended that 40 pounds of molasses per ton be added for grasses and 60 to 80 pounds per ton for alfalfa.

Newlander, *et al.* (8) compared the digestibility of alfalfa, timothy, and soybeans as silages and as hays and concluded that, "On a dry-matter basis the silages carried slightly more digestible protein than did the hays. The artificially dried hays carried the most total digestible nutrients, followed in order by the molasses silages, the silages without molasses treatment and the sun cured hays, the latter two being about equal."

A number of the more commonly grown hay and pasture crops were used for making grass silage in these experiments. The results of the chemical analyses from similarly treated crops are assembled in Table 4.

TABLE 4.—*Composition of grass silage made from various crops.*

Crop	Stage of maturity	Actual composition		Composition on oven-dry basis				
		Moisture, %	Protein, %	Protein, %	Fat, %	Crude fiber, %	Ash, %	N-free extract, %
				1938				
Alfalfa....	1/3 bloom	74.0	3.98	15.31	2.76	26.55	6.52	48.86
Red clover	Early bloom	79.4	3.31	16.08	3.16	26.19	5.65	48.92
Timothy..	Early bloom	69.6	2.09	6.88	2.95	36.17	2.76	51.24
Millet....	Late bloom	81.5	1.45	7.84	2.07	33.16	9.20	47.73
				1939				
Alfalfa....	Early bloom	74.0	4.38	16.82	3.66	29.15	8.30	42.07
Timothy..	Early bloom	67.7	2.30	7.12	2.87	36.94	4.38	48.67
Mixture...	Early bloom	71.4	3.57	12.51	2.95	30.68	5.65	48.21
Sudan grass	Heading	80.6	1.69	8.71	2.58	30.35	6.34	52.02

Alfalfa and red clover both made excellent silage with a high protein content of about 16%. A mixture of timothy and legumes averaged about 12% protein content in the silage made. Timothy, millet, and sudan grass silage were similar in protein content of about 8%. The figures are not entirely comparable since the crops were not taken from the same plat, but they give a fair indication of what composition may be expected from these crops when made into silage.

In addition to the mason jar silos from which samples were taken for chemical analyses, there were a large number from which the silage produced was examined only for general appearance, moisture content, odor, and apparent feeding condition. Several additional crops, stages of maturity for silage, and amounts of preservative were included. The results obtained will be mentioned briefly. For these comparisons 2% molasses for the grasses and 3 to 4% for the legumes and mixtures were generally used.

Kentucky bluegrass when clipped at a stage that would be comparable to average pasturage made good silage with a protein content similar to early cut alfalfa or clover. Winter rye also made very satisfactory silage when cut at an early stage. Red clover and alfalfa when cut before blossoming tended to make a soggy and over-acid silage. Much better appearing silage was obtained when these crops were allowed to reach the full bloom stage before harvesting.

Soybeans ensiled alone when the pods were beginning to fill made very fine silage. Soybeans, millet, soybean-sudan, and millet-sudan mixtures were also very satisfactory for silage purposes.

SUMMARY

A number of grass and legume crops were used for making silage, both alone and in mixtures. Two-quart mason jars were used as miniature silos. Silage prepared in this way was very similar in proximate analysis for conventional feed constituents and in general appearance to silage from the same sources preserved in bags in a large silo filled with grass silage. The chemical composition of several crops on an oven-dry basis was very similar whether preserved as silage in a large silo, in a small tile silo, or in a mason jar silo. The same was also true when these analyses were compared with those of the green material as harvested or after this was cured for hay.

Molasses and phosphoric acid were compared as preservatives. Each material was used at several rates. Both the molasses and the phosphoric acid proved very satisfactory. The amount of preservative used was apparently of less importance than the moisture content and stage of maturity of the material ensiled.

When different crops were ensiled at various stages of maturity, a decrease in protein content with increase in maturity of the crop was noted. Clover and alfalfa ensiled before blooming did not make as satisfactory silage as when allowed to reach full bloom.

Clover, alfalfa, and soybeans made silage with a high protein content and generally excellent quality when harvested at the usual stage of maturity for hay. They were also used as parts of mixtures with other crops with good results. Millet, sudan grass, rye, timothy, and Kentucky bluegrass were other crops satisfactorily ensiled by these methods.

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EFFECTIVENESS ON COTTON SOILS OF GRANULATED MIXED FERTILIZERS OF DIFFERENT PARTICLE SIZE[1]

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THE manufacture of fertilizer materials and fertilizer mixtures in grains of approximately uniform size and shape has received consideration as a means of improving their physical properties. This need has become more pressing with the increased amount of fixed nitrogen used in fertilizer mixtures. Many of these newer products are hydroscopic in nature and lack the conditioning effects of the natural organic nitrogen carriers which they are replacing.

Ross and Hardesty and their associates (3, 4, 8, 9),[3] who have developed methods for the production of mixed fertilizers of different particle size, have pointed out that granulation of fertilizer mixtures reduces caking, prevents segregation, improves the drillability of the mixture, decreases handling charges, eliminates the necessity of using high priced conditioners, and is advantageous in preventing the loss of nitrogen that results when ammoniated mixtures containing dolomitic limestone are in storage. Granulated fertilizers of uniform particle size have an added value in that they can be distributed more uniformly by the common type of fertilizer distributor.

Other factors of interest include the movement and reaction in the soil solution of the nutrients in granulated fertilizer of various particle size, their effect on seed germination, rapidity of plant emergence above ground, plant viability, and crop yield. In this paper the results of field experiments with cotton and laboratory studies on some of these factors are considered. Preliminary informal reports have previously been made (1, 2, 5, 6, 10). Mehring and his associates (7) have reported the results of some agronomic experiments with granulated fertilizer mixtures applied to cotton in 1931–33. Their data show little difference in yield resulting from use of different size particles of three fertilizers tested. However, the smaller size granulated fertilizers of their experiments, as an average, gave slightly larger yields.

EXPERIMENTAL PROCEDURE

The fertilizer used in these experiments was a 6–8–4 (N-P_2O_5-K_2O) analysis prepared from 4 units of ammonium sulfate, 2 units of urea, 8 units of superphosphate, and 4 units of potassium chloride. Sufficient dolomitic limestone was incorporated in the mixture to make it non-acid forming.

Approximately 2.5 tons of fertilizer were prepared for these experiments over a period of 3 years. The dry materials were mixed and ground to pass a 40-mesh

[1]Cooperative studies of granular fertilizers between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the North Carolina, South Carolina, and Georgia experiment stations. Received for publication December 16, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 324.

screen. This powdered mixture was again thoroughly mixed and divided into two portions. One portion was used in the field experiments without further treatment and the other portion was granulated by the method of rotary drying (3) to form granules of the desired size. This method of granulation consists in adjusting the moisture content of the mixture by the addition of water, if necessary, to the optimum for the mixture to be granulated, raising the mixture to a temperature of 60° to 100° C while rolling or tumbling it in a rotary cylinder until granulation occurs, then cooling the granular product and drying it when necessary.

The conditions under which granulation is obtained vary greatly among different materials and mixtures. Thus, fresh den superphosphate does not require the addition of any water since there is already sufficient solution phase present to cause granulation at an elevated temperature. Neither is it necessary to dry artificially the granular product prepared from fresh den superphosphate, especially if it is allowed to cure for a few days subsequent to the granulation treatment. Some mixtures containing large amounts of readily soluble, easily fusible salts, such as urea or ammonium nitrate, may require as little as 6% moisture for satisfactory granulation. Thus, many mixtures of this type which normally contain 6% or more of moisture require no addition of water when they are granulated at elevated temperatures.

The optimum content for the granulation of the mixtures described in this paper was 11.5% moisture. The necessary quantity of water was applied as a fine spray to the mixture while it was being tumbled in a fertilizer mixer. When the moisture had become thoroughly distributed throughout the mass the mixture was subjected to cascading action in a rotary grinder while being heated to a temperature of 72° C in the presence of a non-drying atmosphere. The resulting moist granules were then dried in a rotary dryer to a moisture content corresponding to that of the original powdered material. Approximately 93% of the dried granulated product ranged between 4 and 20 mesh in size. The material was screened to remove the oversize and fine materials which were ground to pass a 40-mesh screen and returned to the process. The dried granular product was divided into three different sizes, namely, 4 to 6 mesh, 5 to 10 mesh, and 10 to 20 mesh, and these sizes were used in the field experiments.

A 6–8–6 analysis was used in 1939, prepared from similar materials but containing 6 units of potash. In considering the data, the slight change in potash content in 1939 has been ignored for purposes of averaging, statistical calculation, and discussion. The results from the granular materials were compared with those obtained from the powdered fertilizer of the same composition formed by grinding the material to pass a 40-mesh sieve. A non-granulated standard fertilizer of the same composition as the granulated and powdered materials was included in the 1938 and 1939 tests. This contained powdered material and small granules of various sizes as is the case in ordinary commercial mixtures. These fertilizers were applied to cotton grown in replicated plot tests on representative soils of the eastern part of the cotton belt. The soil types and location of the experimental fields were as follows: Cecil sandy clay loam at Clemson College, S. C.; heavy Cecil loam at the Georgia Experiment Station, Experiment, Ga.; Orangeburg very fine sandy loam at the Pee Dee Experiment Station, Florence, S. C.; Norfolk sandy loam at the Upper Coastal Plain Experiment Station, Rocky Mount, N. C.; and Norfolk coarse sand at the Sandhill Experiment Station near Columbia, S. C.

The 1937 experiments were planted by L. G. Schoenleber of the Bureau of

Agricultural Chemistry and Engineering with the combination planter-distributor developed for experimental purposes by the Farm Mechanical Equipment Research Division of the Bureau of Agricultural Chemistry and Engineering. Each of the fertilizers was placed in two positions relative to the seed, *viz.*, in narrow bands 2.5 inches to each side of and 3 inches below the seed level, and in a single band about 1.75 inches wide and 3 inches under the seed. In 1938 and 1939, the fertilizer was applied by hand in a placement comparable with farm practices at the various location. It was distributed in a band about 3 inches below the intended seed level, lightly mixed with the soil, bedded on, and seed planted. The fertilizer was applied at the rate of 600 pounds per acre in all the experiments. No side-dressing was used. Chopping, cultivating, harvesting, and other agronomic operations followed usual farm practices.

Observations included periodic germination counts to determine possible fertilizer injury to the seed and determinations of concentration of soluble salts in the soil near the fertilizer band, leaching of nutrients from the fertilizer granules, and yield of seed cotton.

RESULTS

PLANT EMERGENCE AND STAND

The germination or plant emergence from the replicated plots of each treatment of the experiments at Florence and Columbia, S. C., is available for all three years, and average data from the Clemson College and Rocky Mount, N. C., experiments for 1937. The plant emergence counts made at close intervals show the same relation as the final number of plants in plots from each of the fertilizers. The data in Table 1 show the final number of plants only. The detailed data are given in the preliminary reports cited above.

No significant difference in plant emergence resulted from the use of the different particle size fertilizers in the various experiments, although there was a trend when all the experiments are considered as a whole for the larger particle size fertilizers to reduce the stand slightly more than the finer particle fertilizers. Not a great deal of difference in plant stand occurred by placement of fertilizer under the seed as compared to side placement, except in the Rocky Mount experiment when the under seed placement severely injured the seed with each of the fertilizers. This result was undoubtedly caused by fertilizer injury due to placement. There was no consistent trend due to particle size.

CONCENTRATION OF SOLUBLE SALTS

Soluble salts in the soil of the seed and plant root zone, above the fertilizer band in case of below seed placements, and between the fertilizer bands in case of side placements, were determined at approximately 10-day intervals during the 1937 cotton growing season at the Sandhill and Pee Dee Experiment Stations. Each sample was a composite of ten borings taken in the root zone, hortizontally and parallel to the center of the fertilizer band with a 1-inch cork borer. The soil was air dried and a suspension of 100 grams of soil and 200 cc of distilled water was tested for total soluble salt content by the conductivity method.

TABLE 1.—*Effect of granulated fertilizers of different particle size on cotton plant emergence or stand as measured by number of plants per plot.*

Soil type and location	Size of granules				Standard fertilizer*
	4–6 mesh	5–10 mesh	10–20 mesh	Through 40 mesh	
1937					
Cecil sandy clay loam, Clemson College, S. C.:					
Fertilizer applied to side of seed........	224	212	216	200	—
Fertilizer applied under seed...........	192	203	212	211	—
Norfolk coarse sand, Sandhill Exp. Sta., Columbia, S. C.:					
Fertilizer applied to side of seed........	157	155	144	148	—
Fertilizer applied under seed...........	152	149	134	147	—
Orangeburg very fine sandy loam, Pee Dee Exp. Sta., Florence, S. C.:					
Fertilizer applied to side of seed........	149	119	181	167	—
Fertilizer applied under seed..........	151	159	144	164	—
Norfolk sandy loam, Upper Coastal Plain Exp. Sta., Rocky Mount, N. C.:					
Fertilizer applied to side of seed........	280	270	300	345	—
Fertilizer applied under seed...........	100	75	100	150	—
1938					
Norfolk coarse sand, Sandhill Exp. Sta., Columbia, S. C.†:................	287	327	324	348	346
Orangeburg very fine sandy loam, Pee Dee Exp. Sta., Florence, S. C............	579	587	574	597	569
1939					
Norfolk coarse sand, Sandhill Exp. Sta., Columbia, S. C.†:................	257	261	324	269	290
Orangeburg very fine sandy loam, Pee Dee Exp. Sta., Florence, S. C............	298	307	306	335	374
Average‡............................	248	250	260	266	—

*Standard fertilizer contained a mixture of powdered and small granules of varying sizes, comparable with a commercial mixture.
†Fertilizer applied in a band 3 inches wide below intended seed level, lightly mixed with soil, bedded on seed planted above the fertilizer.
‡Exclusive of Rocky Mount—under seed placement.
Difference required for significance — $P = 0.05$, = 17.

The soluble salt data are given in Table 2. There was not a very wide difference in the concentration of salts in the soil adjacent to the fertilizer band due to a difference in particle size of fertilizers. However, there is a consistent trend for a somewhat higher concentration of salts with the fine particle fertilizers. The data show that the total salt concentration was relatively high in the early season and decreased in late summer. Larger quantities of salts had moved into the seed zone from placement of fertilizer below the seed than from

TABLE 2.—*Effect of fertilizers of different particle size on soluble salts in soil within the root zone of plants.*

Soil and location	Percentage soluble salts in soil of root zone from fertilizers of particle size indicated							
	Applied 2.5 ins. to the side and 3 ins. below seed level				Applied in a 1.75 in. band and 3 ins. below seed			
	4–6 mesh	5–10 mesh	10–20 mesh	Under 40 mesh	4–6 mesh	5–10 mesh	10–20 mesh	Under 40 mesh
Norfolk coarse sand, Sandhill Exp. Sta., Columbia, S. C.:								
May 1 to June 2, average	0.106	0.091	0.162	0.177	0.129	0.135	0.195	0.234
Aug. 1 to Sept. 14, average	0.064	0.064	0.072	0.089	0.094	0.101	0.124	0.130
Orangeburg very fine sandy loam, Pee Dee Exp. Sta., Florence, S. C.:								
May 3 to June 1, average	0.142	0.110	0.121	0.177	0.161	0.157	0.149	0.172
Aug. 11 to Sept. 15, average	0.063	0.085	0.077	0.087	0.090	0.090	0.114	0.113

side placement. Mehring and his coworkers (7) found a higher soluble salt content in the soil 100 days after fertilizer application when the coarser grain fertilizer had been used. There was a rainfall over this period of 12 inches, while in 1937 the rainfall over the period was 21 inches. In the experiments reported in this paper the small differences in soluble salts in the soil near the seed was not sufficient to affect seed germination or injure plant stand.

A number of the 4 to 6 mesh granules were recovered at the end of the 1937 season from the Pee Dee and Sandhill experiments and some were collected in January 1940 from the 1939 experiment at the Sandhill Station and were analyzed to determine the change in plant food content. The data are given in Table 3. The granules lost nearly half their original mass during the time they were in the soil.

TABLE 3.—*Composition of 4 to 6 mesh granulated fertilizer when applied and after remaining in the soil through the crop season.*

	Composition of granules			Nutrients remaining in granules, per cent	
	When applied (in April)	In Sept. in Norfolk coarse sand	In Sept. in Orangeburg very fine sandy loam	In Sept. in Norfolk coarse sand	In Sept. in Orangeburg very fine sandy loam
	1937				
Average weight of granules, grams	0.063	0.033	0.046	—	—
Insoluble matter, %	3.45	8.58	11.46	—	—
Nitrogen (N), %	6.14	0.03	0.05	0.3	0.6
Phosphoric acid (P_2O_5), %	7.50	4.65	3.48	32.6	33.9
Potassium (K_2O), %	4.03	0.19	0.13	2.5	2.4
Calcium (CaO), %	21.81	29.15	28.56	70.2	95.6
Magnesium (MgO), %	5.75	9.47	8.91	86.3	112.9
Ca/Mg, ratio	3.79	3.25	3.21	—	—
	1939				
Average weight of granules, grams	0.063	0.037	—	—	—
Insoluble matter, %	3.45	14.96	—	—	—
Nitrogen (N), %	6.14	0.04	—	0.4	—
Phosphoric acid (P_2O_5), %	7.50	3.82	—	30.0	—
Potassium (K_2O), %	6.00	0.18	—	1.8	—
Calcium (CaO), %	19.83	26.17	—	77.6	—
Magnesium (MgO), %	5.23	7.75	—	87.1	—
Ca/Mg, ratio	3.79	3.38	—	—	—

The analyses of the residual material show an increase in insoluble matter part of which was probably soil adhering to the granules. Nitrogen and potash had been largely removed but considerable phosphorus remained. Removal of the more soluble materials resulted in an increase in the percentages of the more insoluble calcium and mag-

nesium salts of which the fertilizer was composed. The change in calcium content of the granules was less than that of magnesium as shown by the calcium-magnesium ratios, indicating greater removal of the gypsum contained in the superphosphate than solution of the dolomite used as filler. The percentage composition of the residual material was calculated to the original weight basis, using the original and residual weights of the particles corrected for the change in insoluble material in order to determine how much of the plant food applied remained in the soil at the end of the crop season. Different granules were used for the weight determinations and for the chemical analyses of the 1937 samples. A difference in average weight of the material used in the two determinations is doubtedless responsible for the apparent discrepancy in the case of the calculated values for the plant food remaining in the granules recovered from the Pee Dee experiment. The same material was weighed and analyzed in the 1940 Sandhill samples. The calculations show that nearly all of the nitrogen, over 97% of the potassium and about two-thirds of the phosphorus contained in the original material were removed during the growing season, presumably by dissolving in the soil solution in the same way as occurs with ordinary fertilizers.

It was observed when the granules were collected that a number of them had been penetrated by small roots, indicating that the residual plant food within the granule might be available to the crop. Thus the chemical and visual evidence support the yield data in showing that granulation does not render the nutrients less available than those in ordinary fertilizer and the total salt determinations made at intervals during the growing season fail to show any wide differences in rate of availability due to use of different size particles.

Mehring, *et al.* (7) analyzed the soil from the fertilizer zone and found that most of the nitrogen had disappeared but that a large part of the phosphorus was still present in their samples after 100 days. They also found some potash, the amount recovered being greater in the case of the finer textured soils. These observations when considered in conjunction with the analysis of the granules alone after they had been exposed in the soil show that phosphate is leached from the fertilizer granule and fixed in the surrounding soil, and that nitrogen is leached from the granule and does not remain in the soil for 100 days.

YIELDS

Yields of seed cotton from all the experiments except one (Table 4) were obtained and their significance determined by the method of variance (11). The 1937 experiment at the Pee Dee Station was abandoned because unseasonably cool weather at germination time followed by severe aphid injury ruined the stand of cotton. The data from the Rocky Mount experiment of 1937, where the fertilizer was placed under the seed, were not included in the general average nor in the statistical calculations because the serious germination injury mentioned above affected the yields in a highly irregular manner and only those plots to which the powdered fertilizer was applied produced reasonably satisfactory results. The general average for each

separate year and the general average for the 3 years showed a nonsignificant trend for the largest size particle to produce the most seed cotton.

In an earlier work by Mehring and his associates it was found that the powdered fertilizer gave slightly larger yields than the coarsest particle fertilizer. Rainfall during the growing seasons of 1937, 1938, and 1939 was greater than normal at all locations and was less than normal during the corresponding period of the earlier experiments. This might have a bearing on the slight difference in response to the fertilizers.

DISCUSSION

From the results of the agronomic and laboratory work with granulated fertilizers of various particle size it seems that granulation does not interfere with plant food availability nor does granulation materially change the effect of fertilizers on cotton plant emergence or yield. The granulated fertilizers were possibly inferior in their effect on plant emergence and slightly superior in crop producing power to ordinary or powdered fertilizers of the same composition and under the same conditions as these experiments. There was no significant preference among the various grade sizes.

In these experiments the standard and powdered materials were applied with unusual care, in most cases by hand on small plots, and there was no segregation of the components as may happen with some nongranulated mixtures and with certain types of fertilizer distributors.

While there appears none or but slight advantage of granulated over nongranulated fertilizers on cotton plant viability and production, granulation has certain advantages over ordinary types of fertilizers including comparative freedom from caking while in storage, complete absence of segregation during handling and storage, superior drilling and distribution properties when used in most ordinary fertilizer distributors, and absence of blowing when applied in windy weather.

SUMMARY

Granulated complete fertilizers of 4 to 6, 5 to 10, and 10 to 20 mesh size were compared with powdered and standard materials of the same composition when applied to cotton at five locations in North Carolina, South Carolina, and Georgia during a 3-year period. There were slightly less soluble salts in the soil of the seed zone when granulated fertilizers were used, the quantity decreasing with increase of particle size, but this variation did not significantly affect plant emergence. There was a trend below the level of significance for the larger granules to increase the yield of seed cotton.

Analysis of the 4 to 6 mesh granules recovered from the soil at the end of the crop season showed a loss from the granules of more than 99% of the original nitrogen, about 97% of the original potassium, and about two-thirds of the original phosphorus. Losses of magnesium and calcium were about 30% and 15%, respectively, in Norfolk coarse sand and apparently somewhat less in Orangeburg very fine sandy loam.

TABLE 4.—*Yields in pounds per acre per acre of cotton from fertilizers of various particle sizes.**

Soil type and location	Size of granules				Standard fertilizer†	Required for Sig. Diff. P=0.05
	4–6 mesh	5–10 mesh	10–20 mesh	Through 40 mesh		
1937						
Cecil sandy clay loam, S. C. Exp. Sta., Clemson College, S. C.:						
Fertilizer applied to side of seed	2,174	2,203	2,180	2,011	—	419
Fertilizer applied under seed	2,254	1,988	2,163	2,070	—	393
Cecil clay, Ga. Exp. Sta., Experiment, Ga.:						
Fertilizer applied to side of seed	448	367	358	370	—	73
Fertilizer applied under seed	358	501	370	461	—	131
Norfolk coarse sand, Sandhill Exp. Sta., Columbia, S. C.:						
Fertilizer applied to side of seed	473	446	478	418	—	99
Fertilizer applied under seed	488	499	446	449	—	169
Norfolk sandy loam, Upper Coastal Plain Exp. Sta., Rocky Mount, N. C.:						
Fertilizer applied to side of seed	1,336	1,370	1,540	1,522	—	214
Fertilizer applied under seed	474	344	550	1,058	—	193
Average‡	1,076	1,053	1,076	1,043	—	78

1938						
Cecil sandy clay loam, S. C. Exp. Sta., Clemson College, S. C.§	1,254	1,275	1,224	1,279	1,292	219
Cecil clay, Ga. Exp. Sta., Experiment, Ga	748	759	788	791	725	53
Norfolk coarse sand, Sandhill Exp. Sta., Columbia, S. C	392	330	359	322	298	113
Orangeburg very fine sandy loam, Pee Dee Exp. Sta., Florence, S. C	2,391	2,516	2,520	2,321	2,263	340
Average sandy loam, Upper Coastal Plain Branch Sta., Rocky Mount, N. C	1,363	1,238	1,190	1,152	1,155	434
Average	1,230	1,224	1,216	1,173	1,147	71
1939						
Cecil sandy clay loam, S. C. Exp. Sta., Clemson College, S. C.§	1,820	1,750	1,849	1,779	1,785	235
Cecil clay, Ga. Exp. Sta., Experiment, Ga	1,306	1,306	1,195	1,366	1,286	207
Norfolk coarse sand, Sandhill Exp. Sta., Columbia, S. C	1,023	990	1,099	944	980	159
Orangeburg very fine sandy loam, Pee Dee Exp. Sta., Florence, S. C	2,884	2,859	2,715	2,822	2,777	146
Norfolk sandy loam, Upper Coastal Plain Branch Sta., Rocky Mount, N. C	1,308	1,049	1,139	1,163	1,276	158
Average	1,668	1,591	1,599	1,615	1,621	103
General average‡	1,295	1,262	1,271	1,249	—	49

*A 6-8-4 analysis used in 1937 and 1938 and a 6-8-6 in 1939.
†Standard fertilizer contained a mixture of powdered and small granules of varying sizes, comparable with a commercial fertilizer mixture.
‡Exclusive of Rocky Mount—under seed placement, 1937.
§Fertilizer applied in a band 3 inches below intended seed level, lightly mixed with soil, bedded on seed planted above the fertilizer.

It is concluded that granulation does not affect plant food availability and that granulated fertilizers should prove superior to ordinary fertilizers under conditions where the latter would segregate or cake or blow when applied during windy weather.

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A RAPID AND SIMPLE METHOD FOR DETERMINING MOISTURE IN FORAGES AND GRAINS[1]

R. Q. PARKS[2]

RECENT advances in agricultural science have intensified the need for a rapid, inexpensive, and fairly accurate method for determining the percentage of moisture in plant materials. Such a method would be of use not only to investigators of many types of forage and cereal problems, but would also enable the farm operator to conduct more efficiently and economically such operations as putting up silage, making hay, harvesting wheat, cutting or husking corn, etc. To fulfill the need of practical agriculture for moisture control in such operations, a method is required which would cover a continuous moisture range of from 10 to 85%, and which could be applied to both grains and forage materials.

LITERATURE REVIEW

So far as the author is aware, there is at present no widely adaptable method for determining moisture in plant tissues that is both rapid enough for practical use and financially within the reach of the average farmer.

The standard method for determining percentage moisture in plant tissues is to measure the loss in weight after heating the material in a hot air oven (1).[3] The time required varies from 1 hour to 3 days, depending on the temperature used and the fineness of subdivision of the sample. Such determinations obviously are not well adapted to practical use on the farm.

The method of determining moisture by distillation with toluene (1) is satisfactory in accuracy but impractical because of the time and equipment required.

An apparatus which is designed to force heated air through the plant material is now commercially available and is sufficiently rapid and accurate for moisture determinations on forage materials but involves the use of equipment which the average farmer is either unable or unwilling to purchase. Monroe and Perkins (12) have reported favorably on the speed and accuracy of such an apparatus.

The Tag-Heppenstahl electric moisture meter (4) is satisfactory if the material is of uniform moisture content but requires expensive equipment and is limited in use to small grains and shelled corn of from 7 to 31% moisture. This method is sufficiently accurate for most practical purposes over the moisture range ordinarily encountered in commercial grain.

Featherstone (6) has recently reported on a rapid laboratory procedure for the determination of moisture in plant materials. This method is based upon the rise in temperature which results when plant material is mixed with concentrated sulfuric acid and is used most successfully in the moisture range of from 15 to 50%.

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[2]Assistant in Agronomy. The author is indebted to R. M. Salter and J. C. Carrol of the Ohio Agricultural Experiment Station, Dr. R. D. Lewis of The Ohio State University, and Dr. R. E. Yoder of the Soil Conservation Service, for aid and suggestions during the course of this investigation.

[3]Figures in parentheses refer to "Literature Cited", p. 334.

The method for determining moisture in plant tissues which this paper proposes involves the use of calcium carbide as a dehydrating agent. The use of calcium carbide has been proposed for determining moisture in many materials, including petroleum, fabrics, paper, and flour (11). Sibirskii (16) has applied this reagent to the determination of moisture in soils, using loss in weight during the reaction as the index of soil moisture. Fukunga and Dean (7) have proposed a modification of this method in which the pressure produced by the generation of acetylene was measured with a 30-pound steam gauge. The safety of this technic is questionable since Perkin and Kipping (13) state that acetylene gas is explosive when under a pressure of 2 atmospheres or greater.

So far as the author has been able to determine, calcium carbide has not been suggested before for use in a direct determination of moisture in plant tissue, although Chopin (3) used the reaction of water vapor with calcium carbide as an index of the time required to dry a sample of chopped plant material heated electrically at about 200° C.

EXPERIMENTAL

Calcium carbide reacts with water according to the following equation:

CaC_2	+	$2\ H_2O$	=	$Ca(OH)_2$	+	C_2H_2	+	30,400 cal.
Calcium carbide		Water		Calcium hydroxide		Acetylene (gas)		

in which 36 grams of water react to give 26 grams of acetylene gas and 30,400 calories (8) of heat. The water taking part in this reaction may be in liquid or vapor form or in a mixture with other chemicals, such as water in plant sap.

When an excess of calcium carbide is added to a given weight of plant material and mixed, a loss of weight occurs which can be used as an index of the percentage moisture of the original sample.

A satisfactory method of carrying out this carbide reaction was found to be in a seamless tin container 3¾ inches in diameter and 2½ inches deep. Nine holes (½ inch in diameter) were drilled in the top and a coarse filter paper glued inside the lid. The purpose of the filter paper is to prevent loss of powdered carbide due to convection currents and at the same time allow ready escape of the acetylene gas formed. An excess of CaC_2 was placed in the lid and 30 grams of plant material weighed into the bottom half of the container. After obtaining the total weight (the lid with the carbide plus the container and its contents), the carbide was poured from the lid into the container. After placing the lid firmly in place, the container was alternately shaken and weighed until further loss in weight had ceased.

An examination of Fig. 1 shows the relationship found between oven-determined percentages of moisture and losses in weight of mixtures of calcium carbide and 30-gram samples of plant materials. The ordinate denotes the losses in weight of 30-gram plant samples during this reaction. The percentage moisture of the original plant material, determined by measuring loss in weight caused by heating in a hot air oven at 100° C, is plotted as the abscissa. Although most of the common forage materials and small grains have been included

in the determinations, all fit the same curve within 3% or less of the oven-determined moistures. Each point represents the average of duplicate determinations, which usually agree within 2 or 3% moisture.

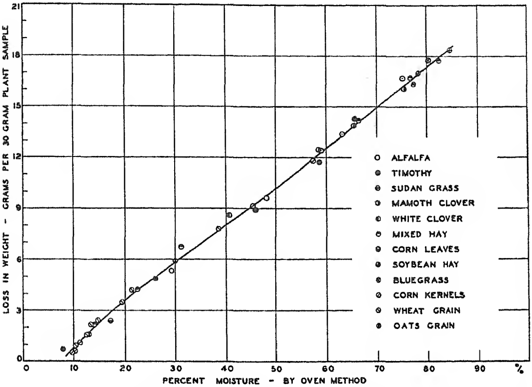

FIG. 1—Effect of moisture content and type of plant material on loss in weight per 30-gram plant sample, mixed with an excess of calcium carbide.

The question immediately arises as to whether all the water present in the plant tissues reacts to form acetylene, and if so, how contact is made between the carbide and water contained in the relatively thick stems of alfalfa or soybean plants. The representative data of Table 1 show that apparently all the water present reacted when the samples contained around 40% moisture or more. In the case of samples below this moisture range, the slight deviations of the points from the curve of Fig. 1 show that of the water present at each moisture content, a definite portion takes part in the reaction.

TABLE 1.—*Effect of varying moisture contents of plant samples on the proportion of water reacting with carbide.*

Water (by oven method), %	Water per 30 grams fresh material, grams	Theoretical C_2H_2 loss, grams	Actual loss in weight, grams	Water reacting, %
7.9	2.4	1.7	0.8	49.1
26.0	7.8	5.6	4.9	87.5
40.5	12.2	8.7	8.6	98.8
58.4	17.5	12.6	12.5	99.2
75.0	22.5	16.2	16.7	103.1
82.3	24.7	17.8	17.8	100.0

The most plausible explanation for the complete removal of water from relatively large plant stems seems to be that the reaction between surface moisture and calcium carbide generates sufficient heat to vaporize the water contained in the inner tissues, much as a hot air oven operates. The water vapor thus driven off can then react with the large excess of carbide with which the sample is mixed.

As was previously pointed out, the closeness of fit of the points to the line of the data plotted in Fig. 1 indicates that this reaction may be used as an index of plant moisture from 10 to 85%, regardless of the type of plant tissue being analyzed.

To determine the effect of fineness of subdivision of sample on both the absolute value and the rate at which equilibrium is reached, determinations were made on a sample of alfalfa hay. The results, recorded in Table 2, show that no significant differences in weight losses resulted from samples cut into different lengths, but that the rate at which equilibrium was attained was affected. Although one might expect best contact between the carbide and the sample cut in the rotary blade food chopper, the matting effect on the sample of this instrument probably accounts for the poorer initial contact and slowing up of the reaction which resulted. Cutting hay samples into approximately ½-inch lengths with shears is a satisfactory procedure.

TABLE 2.—*Effect of degree of subdivision of plant sample on rate and extent of reaction with calcium carbide.*

Method of cutting sample	Length of pieces, inches	Loss per 30-gram sample, grams	Moisture content (by CaC_2), %	Moisture content (by oven), %	Time for equilibrium, minutes
Rotary chopper...	$\frac{1}{16}$	14.2	67	66.0	10
Shears...........	¼	14.1	66	66.0	5
Shears...........	½	14.3	67	66.0	10
Shears...........	1	14.0	66	66.0	20

It is also possible to make determinations with this method on all types of grains as long as the kernels are broken open. Whether the grains are cut lengthwise with a knife or pounded with a hammer or other instrument is immaterial, as long as the seed coat is broken.

That the amount of carbide used is of no importance, as long as an excess is present, is shown by the data in Table 3. As the sample used in this experiment was nearly as moist as any to which this method would be applied, 100 grams of carbide is deemed sufficient. Since an excess of carbide interferred in no way with the rate or extent of the reaction, the 100-gram rate could also be used on plant samples of lower moisture content.

The calcium carbide used was of a technical grade, ground in a Braun Planetary Pulverizer. To determine the possible effect of using carbide of varying degrees of fineness, a set of determinations was made on alfalfa-timothy hay at two moisture contents, *viz.*, 66.6% and 22.6%. The results, recorded in Table 4, show that as far as the final value is concerned, all sizes of carbide below 25 mesh are equally satisfactory. The fineness of grinding did, however, have an

TABLE 3.—*Effect of amount of carbide on rate and extent of reaction with plant material.*

Carbide used per 30-gram plant sample, grams	Weight loss per sample, grams	Moisture content (by CaC_2), %	Moisture content (by oven), %	Difference in measurements, %	Time for equilibrium, minutes
20	12.0	58	79.4	21.4	25
60	16.9	78	79.4	1.4	25
100	17.6	80	79.4	0.6	10
140	17.6	80	79.4	0.6	10

effect on the rate at which equilibrium was attained. While the technical grade of carbide gave fairly good results, it was found more satisfactory to run this material through a grinder or pulverizer. The "fine ground" calcium carbide put out by several of the chemical supply houses is also satisfactory. Material with a good distribution of particle sizes gave better results than samples of uniformly large or small particle size. The cost of calcium carbide (technical grade) for a single determination is between 1 and 2 cents.

TABLE 4.—*Effect of size of calcium carbide particles on the rate and extent of reaction.*

Size of carbide sample particles, meshes per inch	Loss in weight, grams	Moisture content (by CaC_2), %	Moisture content (by oven), %	Difference in measurements, %	Time for equilibrium, minutes
		Sample A			
10–25.......	3.1	18.2	22.6	4.4	15
25–50.......	4.0	21.5	22.6	1.1	15
50–100......	4.5	23.8	22.6	1.2	10
<100........	4.3	22.8	22.6	0.2	10
Commercial:*					
Ground....	4.2	22.6	22.6	0.0	15
Unground	3.8	21.0	22.6	1.6	15
		Sample B			
10–25.......	13.6	64.0	66.6	2.6	30
25–50.......	14.0	66.0	66.6	0.6	25
50–100†.....	—	—	—	—	—
<100........	—	—	—	—	—
Commercial:*					
Ground....	14.2	66.4	66.6	0.2	20
Unground	14.0	66.0	66.6	0.6	25

*The ground material had 22% of 50 mesh or finer, while the unground had less than 1% of this finer material.
†On this relatively moist sample, the reaction with the 50–100 mesh and <100 mesh carbide particles was so rapid that sufficient heat was generated to char the sample.

Since the time in which a determination of plant moisture can be made is an important factor in the use of such a method as the one herein described, a series of measurements was made to determine the

effect of varying moisture contents on the time required to complete the reaction. The results of this experiment, plotted in Fig. 2, show that 15 minutes is sufficient time for completion of the reaction regardless of the initial moisture content of the plant material. The time required to reach equilibrium will depend somewhat, of course, upon the number of times the sample is shaken during the initial reaction period.

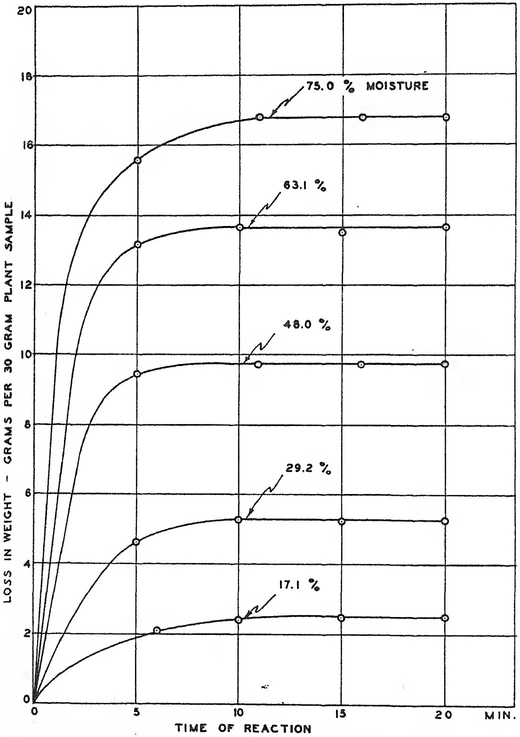

FIG. 2.—Effect of moisture content of plant samples on rate at which equilibrium is reached.

Although this method may be used with any size of plant sample and on any suitable scale or balance set, it was deemed necessary, if the method was to be of greatest practical value, to devise a balance which would read directly in percentage moisture, would be sufficiently sensitive, and yet would be durable enough for field and farm use. Figs. 3, 4, and 5 show in operation an experimental model of the balance which was the outgrowth of this phase of the investigation.

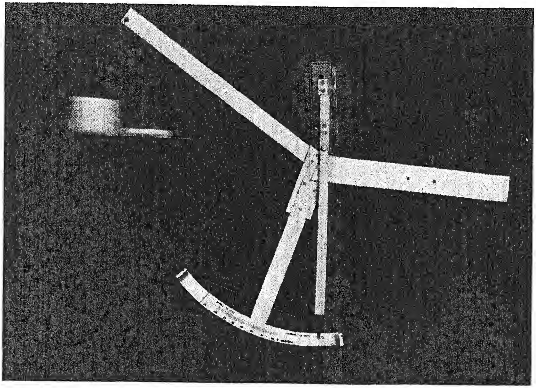

FIG. 3.—Calcium carbide added to the lid until the indicator points to the red line.

The essential features of this balance are two arms (one for the pan and container, the other a counterpoise) which both point upward and meet at an angle of 150°; and a third arm, or ballast, which controls the extent of swing, without affecting the sensitivity through the range being considered. The arms pivot on a knife edge made from a tool steel bolt. The arrow is arrested by stops at both ends of the scale which prevent excess swing and hold the balance at rest while the container and part of the carbide are being added. Deflection begins when all but about 10 grams of the carbide has been added.

In order to determine the magnitude of possible variations resulting from the use of the method and the balance, and to determine the personal error involved, several individuals were asked to make duplicate analyses of plant samples of varying moisture contents. The results of these determinations are contained in Table 5.

PROCEDURE ADOPTED

The following are brief instructions for making a determination with this equipment:

1. Every care should be used to obtain a representative sample. Because of the simplicity and low cost, duplicate or triplicate samples may be used to check on variations due to sampling.

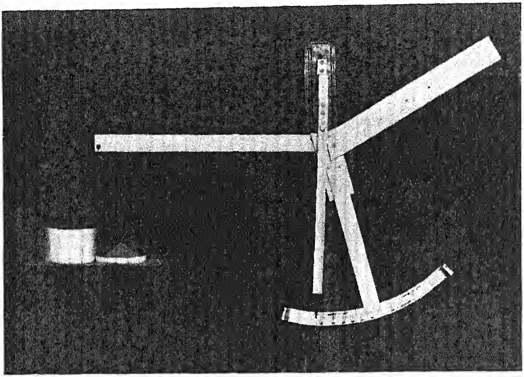

FIG. 4.—Plant sample added to the bottom half of the container until the indicator reaches the black line.

TABLE 5.—*Extent of variations in results, including personal error.*

Operator	Moisture content determined, %	Average of two determinations, %	Moisture content (by oven), %	Difference in moisture content, %
A	72 77	74.5	72.1	2.4
B	37 40	38.5	39.7	1.2
C	30 32	31.0	29.6	1.4
D*	23 24	23.5	22.6	0.9

*Operator D, the author, was the only one of these individuals with a previous knowledge of the equipment and its operation.

2. Cut the sample into approximately ½-inch lengths with a pair of shears. (For a grain sample break the seed coats by crushing or pounding.) Mix and place in a stoppered jar unless the determination is to be made immediately. Significant moisture losses will occur if the sample is left uncovered for more than 15 or 20 minutes.

3. Place the container and lid on the balance pan, and add carbide to the *lid* until the indicator reaches the red line.
4. Add plant sample to the bottom half of the container until the Indicator reaches the black line.
5. Pour carbide from the lid to the container,[4] place the lid firmly on the container, and shake occasionally.[5] If the container becomes too hot to hold in the hand, it may be held with a cloth, but should be shaken less frequently than a drier sample.

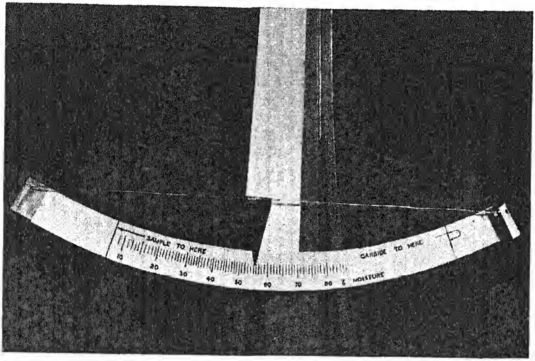

FIG. 5.—Close-up of the scale on which percentage moisture is read directly. The linear distance on the scale from 10 to 85% is about 7 inches.

6. After about 15 minutes, replace the container on the balance pan and read percentage moisture on the scale. If several determinations are being run simultaneously samples may be allowed to stand as long as an hour before the final weighing. Duplicate determinations should be made on all samples, and for grains of from 10 to 15% moisture, it is advisable to run and take the average of three determinations.
7. Dispose of the contents of the container where it will not be eaten by chickens or livestock. A bucket or paper bag make a satisfactory receptable.

[4]If the carbide is finely ground, the loss of a small amount of powder material during this operation is unavoidable but is not of sufficient order of magnitude to influence the results.

[5]Three or four periods of shaking during the course of the reaction are all that is required. When measuring a sample that is expected to run 70% moisture or higher, it is advisable after pouring the carbide onto the sample, to wait 5 minutes before placing the lid on the container. Then proceed as above. This allows the dissipation of excess heat which might char the sample.

DISCUSSION

This method will, it is believed, make available to farm operators and research workers a practical method of moisture determination which may be readily applied to all the numerous situations in farm practice where moisture control is necessary or desirable.

It has long been recognized that hay should have a rather low moisture content to keep well in the mow. Hay with a moisture content of from 25 to 30% can be stored safely in the ordinary mow (10), but chopped hay should be drier than this to prevent browning and burning. Field baled hay should also be drier than long hay put in the mow. Watson (17) places this figure at around 20% moisture.

Small grains must be combined when at a moisture content of 14% or less to prevent spoilage when stored in bins (9), and for maximum yield corn for grain should not be cut or harvested until the moisture content of the grain has fallen to 40% (60% dry matter).

Eckles (5) was the first to point out that under proper conditions legumes may be preserved entirely successfully in the silo. No preservatives were used in these experiments and 60% moisture was found to give best results. More recent work (2, 14, 15, 18) places this moisture range at from 60 to 70%. Perkins, *et al.* (14) state that the proper control of dry matter is probably the most important consideration in legume grass silage making and that when the moisture content is properly controlled, it is seldom possible to recognize differences in silage made with and without preservatives.

SUMMARY

A simple, inexpensive method has been developed for the rapid determination of moisture in small grains, corn, hay, and silage materials. The determination is based on the relationship between original moisture content of plant tissue and loss in weight when the sample is mixed with an excess of calcium carbide.

A balance was constructed and calibrated to read directly in percentage moisture. The balance operates on the lever principle, but has its greatest sensitivity in the range of the last 10% of the weight added, instead of decreasing its sensitivity with each increment of weight, as is the case with the simple lever balance.

The effects of several variables on moisture determinations by this method were studied. These variables included size of cutting sample, type of plant material, amount and fineness of calcium carbide used, effect of original moisture content on the rate at which equilibrium was reached, and extent of variations in results due to the equipment and to personal error.

It is possible, with the method proposed, to determine percentage moisture in plant tissue to within 3% of the actual moisture content over a range of from 10 to 85% moisture in from 10 to 25 minutes.

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FIELD VERSUS CONTROLLED FREEZING AS A MEASURE OF COLD RESISTANCE OF WINTER WHEAT VARIETIES[1]

R. O. WEIBEL AND K. S. QUISENBERRY[2]

COLD resistance of winter wheat varieties is best measured in field tests, provided the conditions are suitable for differential killing. In field tests the investigator either must wait for a winter of desired severity or go to much effort in distributing the material over a wide area in hopes of getting the desired degree of killing at one or more places.

The development of a rapid and efficient laboratory method for testing the cold resistance of wheat varieties has been the object of much investigation and study. No chemical test for measuring cold resistance yet devised has been consistent enough to be used as a substitute for actual freezing.

The objects of the experiments reported here were (a) to secure additional data concerning the correlation between the reaction of some winter wheat varieties to artificial freezing and winter survival in the field, (b) to determine the extent of agreement between replicated freezing tests made at different periods, and (c) to determine the number of freezing tests necessary to evaluate the hardiness of varieties with an accuracy approaching that obtained in the field.

REVIEW OF LITERATURE

Various workers have shown that certain physical and chemical characteristics of plants or plant tissues are related to winterhardiness. According to Martin (4),[3] these laboratory methods have not been consistent enough to be used with confidence and are not as accurate as carefully conducted field studies.

Artificially produced low temperature and its effect upon plant tissues has been studied by a number of workers. Harvey (1) was one of the first to use mechanical refrigeration in the study of the cold resistance of plants. Martin (4) found that freezing under controlled temperature offered the greatest promise as a laboratory method for measuring the hardiness of wheat plants. High correlations between results of artificial freezing of thoroughly hardened varieties of wheat and survival under field conditions were reported by Salmon (8). Hill and Salmon (2), Laude (3), and Worzella and Cutler (10) found a close agreement between survivals as expressed in controlled freezes and in the field.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr., cooperating. Published with the approval of the Director of the Nebraska Agricultural Experiment Station as Journal Series Paper No. 272. Part of a thesis submitted by the senior writer in partial fulfillment of the requirements for the degree of master of science at the University of Nebraska. Received for publication January 2, 1941.

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[3]Figures in parenthesis refer to "Literature Cited", p. 342.

MATERIALS AND METHODS

Thirty varieties of winter wheat grown in the cooperative Great Plains Uniform Winterhardiness Nursery in 1937 and 1938 were used in this study. These varieties were chosen because of the large amount of information available as to their relative winterhardiness under field conditions. The plants were subjected to controlled low temperatures and their behavior compared with the known winterhardiness as measured in the field.

The experiment was conducted during the two winters of 1936–37 and 1937–38. In both seasons the wheat was seeded outside during the first week of October in cypress flats that were buried with the tops of the flats at the ground level. Three varieties and a Kharkof check were seeded in each flat using 25 kernels per variety, with 12 replications each year. When necessary the plants were watered to keep them in a good growing condition. Field conditions were maintained as nearly as was possible. In both years, the plants reached the tillering stage before going into a dormant condition for the winter.

The flats were taken in and frozen at four dates, approximately November 15, December 5, December 15, and January 15. In this way it was possible to obtain data on the rate at which hardiness was built up as well as on the comparative hardiness of the varieties. One complete set of all varieties was frozen on each of 3 days, during each of the four freezing periods. An interval of 2 days, after the first set was frozen, gave an opportunity to inspect the frozen plants and adjust the temperature for the last two sets.

The freezing was done in the mechanically controlled freezing chambers maintained by the Department of Plant Pathology, Nebraska Agricultural Experiment Station, as described by Peltier (5). Plants were exposed for a 24-hour period beginning at 8:00 a.m., at temperatures ranging from −17° C to −26° C, depending upon the condition of the plants at the time of freezing. The flats then were transferred to a greenhouse maintained at a temperature near 21° C and were kept watered to allow live plants to recover.

Survival counts were made approximately 10 days after freezing. In order to adjust for the variation between flats, varietal survivals are reported in percentages of the average survival of all checks in a replication, rather than as actual survival percentages.

Results of the controlled freezing tests were compared with data obtained from reports of the Great Plains Uniform Winterhardiness Nurseries (6, 7).

RELATIVE HARDINESS OF VARIETIES

The average survivals of each variety in the controlled freezing tests and in the field are presented in Table 1. The survivals are expressed as percentages of the average of the Kharkof checks grown in comparable tests. In the controlled freezing tests Minard × Minhardi (C. I. 8888), Minhardi, and Kanred × Minhardi (C. I. 11726) had the highest 2-year average survivals and were the most cold resistant in each of the 2 years. Standard varieties such as Minturki, Nebraska No. 60, and Cheyenne ranked above Kharkof, while Kanred, Blackhull, and Fulcaster were below.

In the field, Lutescens 0329, Minhardi, and Minard × Minhardi (C. I. 8888) were the most winter hardy. Minturki, Nebred, Cheyenne, and Kanred were more hardy than Kharkof and Blackhull, while Fulcaster was decidedly less hardy. The average survivals in per-

centage of that of Kharkof are based upon from 21 to 301 tests conducted during the period from 1920 to 1938.

TABLE 1.—*Average survival of 30 varieties of winter wheat under controlled low temperatures and in the field in percentage of that of Kharkof in comparable tests.*

Variety	C. I. No.	Controlled freezing, %				Field survival, %
		1936–37	1937–38	2-year average		
				Survival	Rank	
Lutescens 0329	8896	158.1	124.8	141.5	7	132.8
Minhardi	5149	240.9	194.6	217.8	2	123.8
Minard × Minhardi	8888	263.8	191.4	227.6	1	122.6
Kanred × Minessa	8045	202.7	176.7	189.7	4	119.7
Kanred × Minhardi	11726	223.8	181.1	202.5	3	119.6
Minturki	6155	131.6	126.1	128.9	12	116.8
Turkey × Buffum	11741	219.9	155.6	187.8	5	115.5
Marmin	11502	125.1	117.5	121.3	13	114.9
Turkey × Kanred	11725	163.6	141.8	152.7	6	114.6
Minturki × Turkey	11500	155.2	115.0	135.1	10	114.5
Minturki × Marquis	11659	116.5	112.1	114.3	16	114.4
Minturki × Marquis	11501	131.8	108.2	120.0	14	113.6
Minturki × Marquis	11658	131.6	94.6	113.1	17	113.1
Nebred	10094	151.3	125.8	138.6	8	110.6
Turkey × Buffum	11739	135.5	98.8	117.2	15	110.1
Minhardi × Marquis	11657	113.8	109.6	111.7	18	110.1
Cheyenne selection	11666	162.0	113.1	137.6	9	107.5
Nebraska No. 60	6250	123.2	143.6	133.4	11	106.4
Cheyenne	8885	103.0	76.1	89.6	22	105.1
Kanred	5146	64.5	104.7	84.6	23	102.1
Kharkof	1442	100.0	100.0	100.0	19	100.0
Ashkof × Minturki	11724	88.3	92.5	90.4	21	98.4
Wheat × rye	11403	65.2	54.5	59.9	26	96.2
Akron selection	11660	115.5	83.6	99.6	20	92.5
Blackhull selection	11737	54.2	59.1	56.7	28	91.9
Kawvale × Tenmarq	11669	80.7	35.4	58.1	27	91.2
Oro × Tenmarq	11673	59.3	66.7	63.0	24	85.7
Oro × Tenmarq	11672	59.1	62.3	60.7	25	84.1
Blackhull	6251	31.0	33.6	32.3	29	78.4
Fulcaster	6471	8.4	15.0	11.7	30	74.6

With a few exceptions, the varieties ranked the same in the controlled freezing tests in each of the 2 years. The close agreement is indicated by the correlation coefficient of + .9298 between the survivals in 1936–37 and those in 1937–38. There was also good agreement between the survivals at different freezing dates as indicated in Table 2. It will be noted that the correlation coefficients here range from + .6719 to + .8721 and all were statistically significant. When the survivals of each individual freezing date (each an average of three freezes) were correlated with the average of the other three dates, the coefficients ranged from + .7897 to + .8815.

TABLE 2.—*Simple correlation coefficients showing the relationship between average survivals of varieties at different freezing periods.*

Freezing period	Freezing period			Average of three periods excluding one correlated
	Second	Third	Fourth	
		Winter of 1936–37		
First	0.7236	0.8086	0.6719	0.8147
Second	——	0.7539	0.7523	0.8126
Third	——	——	0.7256	0.8331
Fourth	——	——	——	0.7897
		Winter of 1937–38		
First	0.7593	0.7280	0.8203	0.8199
Second	——	0.8721	0.8344	0.8641
Third	——	——	0.7885	0.8308
Fourth	——	——	——	0.8815

From Fisher's tables, 1% point for N = 28 is approximately 0.4640.

COMPARISON OF DATA FROM CONTROLLED TESTS AND FROM THE FIELD

The average survival from the controlled freezing tests and from the field are compared graphically in Fig. 1. The spread in survival was much greater in the controlled freezing tests than from the field, but in general the varieties ranked about the same. Among the exceptions, Lutescens 0329 (C. I. 8886), Minturki (C. I. 6155), and Marmin (C. I. 11502) gave comparatively lower survivals in the controlled tests than would be expected from their field behavior. On the other hand, Nebred (C. I. 10094), Cheyenne selection (C. I. 11666), Nebraska No. 60 (C. I. 6250), and Akron selection (C. I. 11660) had higher survivals in the controlled tests than would be expected from their field performance.

The correlation coefficient between the survivals in the field and in the controlled tests, + .8656, is in agreement with those previously reported for similar studies.

TABLE 3.—*Correlation between survival of winter wheat varieties in the field and in controlled freezing tests during four periods.*

Freezing period	Coefficient of correlation
1936–37	
First	+0.6505
Second	+0.8124
Third	+0.7763
Fourth	+0.7742
1937–38	
First	+0.7735
Second	+0.8296
Third	+0.8231
Fourth	+0.7293

From Fisher's tables, 1% point for N = 28 is approximately 0.4640.

Since four freezing periods were used, an attempt was made to determine if survivals from any one period compared more closely than another with those from the field. The coefficients of correlation are presented in Table 3. All of these values are above + .65, indicating fairly close agreement. In both years the agreement with the field tests was poorest for the first and last freezing tests and best for the second test. From this, it would seem that the best freezing results were obtained during the month of December.

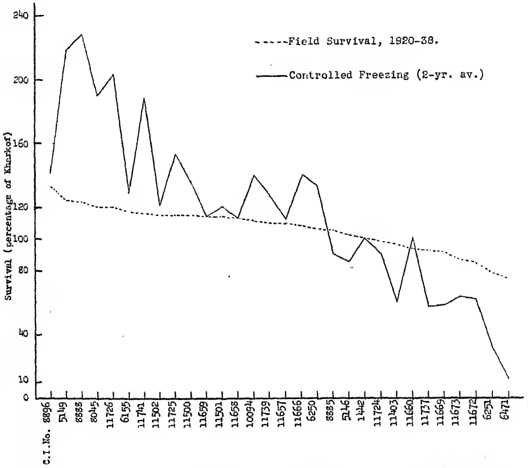

Fig. 1.—Comparison of survivals of the winter wheat varieties under controlled freezing and in the field.

PROGRESSIVE HARDENING OF PLANTS

A record of dates of exposure, temperatures used, and average survivals is presented in Table 4. During the winter of 1936–37 the temperatures used for freezing ranged from –18° C to –26° C and the average survivals from 18.2 to 72.7%. The following winter (1937–38) the temperatures ranged from –17° C to –23° C and the average survivals from 11.0 to 72.6%. These data emphasize the fact that freezing conditions vary from day to day and from period to period. Careful observations of the material must be made to adjust exposure temperatures so that usable data may be obtained.

As the season progressed it was necessary to lower the temperatures in order to get the amount of killing desired. During the 1936–

TABLE 4.—*Exposure and average survival of winter wheat frozen during two winters.*

	Freezing period					
	1			2		
1936–37						
Date frozen..........	Nov. 16	Nov. 19	Nov. 20	Dec. 4	Dec. 7	Dec. 8
Temperature used, °C	−18°	−20°	−20°	−24°	−26°	−26°
Average survival of all varieties, %........	47.5	54.2	27.9	63.7	24.8	18.2
	Freezing period					
	3			4		
1936–37						
Date frozen..........	Dec. 15	Dec. 18	Dec. 19	Jan. 22	Jan. 25	Jan. 26
Temperature used, °C	−25°	−24°	−24°	−24°	−24°	−24°
Average survival of all varieties, %........	29.0	18.6	31.0	72.7	60.4	51.6
	Freezing period					
	1			2		
1937–38						
Date frozen..........	Nov. 15	Nov. 18	Nov. 19	Dec. 3	Dec. 5	Dec. 6
Temperature used, °C	−17°	−21°	−23°	−22°	−21°	−21°
Average survival of all varieties, %........	64.1	17.5	11.0	50.7	55.6	56.3
	Freezing period					
	3			4		
1937–38						
Date frozen..........	Dec. 17	Dec. 20	Dec. 21	Jan. 14	Jan. 17	Jan. 18
Temperature used, °C	−22°	−23°	−23°	−23°	−23°	−23°
Average survival of all varieties, %........	72.6	55.1	38.7	51.5	36.1	43.0

37 season the freezing temperatures were lowered too rapidly and in the second and third freezing period some low survivals resulted. Between the third and fourth periods there was a decided increase in survival with little or no change in exposure temperature. In other words, the maximum hardiness was not obtained until this last period. In 1937–38 there was an increase in survival, with lower exposure temperatures through the third freezing period. Mild weather during the latter part of December and early January seemed to stop

the gain in hardiness, and survivals remained about the same for the fourth period. In this year maximum hardiness was attained about the middle of December. These observations regarding the increase in hardiness are in accord with those of Suneson and Peltier (9).

It was observed that all varieties did not follow the same trend of increasing hardiness, nor did they always retain the same relative position from one freeze to another. Survival percentages for a few representative varieties are averaged by freezing periods for 2 years in Table 5. The average survival of the 30 varieties increased from the first to the second period, decreased slightly in the third, and then increased considerably in the fourth period. Kharkof, Minard × Minhardi, and Minhardi followed the same general trend. Lutescens 0329 and Kanred were relatively low in the first period, increased in survival in the second and third periods, and then decreased in the fourth. Blackhull had lower survivals in the second and third periods than in the other two. Fulcaster was low throughout the test. As might be expected the least change took place between the second and third periods due no doubt to the fact that these freezes were only 10 days apart.

TABLE 5.—*Average survival by freezing periods of some varieties of winter wheat tested for 2 years under controlled low temperatures.*

Variety	C. I. No.	Average survival for freezing period, %			
		First	Second	Third	Fourth
Average of 30 varieties	——	37.0	44.9	40.8	52.6
Kharkof	1442	36.4	42.1	40.5	54.0
Minard × Minhardi	8888	69.4	78.7	78.0	86.5
Minhardi	5149	67.4	69.8	70.0	80.0
Lutescens 0329	8896	31.7	60.5	59.8	54.4
Kanred	5146	34.5	41.7	41.3	23.1
Blackhull	6251	17.0	8.8	10.8	24.1
Fulcaster	6471	4.2	8.0	6.1	3.3

SUMMARY

Thirty winter wheat varieties grown in the Great Plains Uniform Winterhardiness Nursery were subjected to controlled freezing to study winterhardiness.

A coefficient of correlation of + .8656 was obtained when the average survivals from 24 controlled freezing tests made over a 2-year period were compared with those from the field.

The data for the 2 years of controlled tests agreed closely as shown by a correlation coefficient of +.9298. Artificial freezing tests of fall-sown plants gave the best agreement with field results when made in December. The seasonal trend of increased hardiness differed with different varieties.

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RESISTANCE OF CORN STRAINS TO THE CORN EAR WORM[1]

RALPH A. BLANCHARD, JOHN H. BIGGER, AND RALPH O. SNELLING[2]

THE corn ear worm (*Heliothis armigera* Hbn.) is responsible for some loss to field corn in the southern part of the Corn Belt almost every year. During occasional years the injury due to this insect is general throughout the Corn Belt. The relatively low value of the crop per acre precludes the possibility of reducing damage by the application of insecticides or by other direct control methods. The development and use of resistant hybrids seems, therefore, to be the most promising means of materially reducing ear worm damage to dent corn.

Differences among corn strains in the damage they suffered from the corn ear worm have been observed by various workers. Early observations have dealt largely with open-pollinated corn varieties or double-cross hybrids. During recent years, however, inbred lines and single crosses have been studied, and it is now believed that the status of inbred lines as ear worm resistant parents can be best determined by testing them in series of single crosses. Data presented here were obtained at three locations in Illinois during the period of 1937 to 1939.

METHODS

In 1937, the plots were located near Urbana in east-central Illinois. The strains were grown in single rows, 10 hills long, and each strain was replicated four times in randomized blocks. Fifty-one inbred lines and 69 single crosses were studied. Five newly hatched ear worm larvae were placed on the silks of each of several ear shoots of each strain to assure an adequate infestation. The natural infestation further increased the number of ears damaged as well as the severity of the damage.

In 1938, plantings were made at Urbana and also at McClure, in the extreme southern part of Illinois. The Urbana plots consisted of duplicated single rows, 10 hills long. Several ear shoots of each entry were hand-infested with five newly hatched larvae per shoot. The McClure plots were triplicated single rows, 10 hills long.

In 1939,the tests were conducted at McClure. The inbred lines were compared in single-row plots, 10 hills long, replicated four times. The single crosses were planted in 2 × 10-hill plots, replicated five times. Natural infestation was dedepended upon for data from the McClure plots both years.

The ear worm causes injury to the ears at two stages of growth, the developing ear and the maturing corn. The stage of maturity of the corn at the time infestation occurs determines the type of damage. Since the ear worm moth prefers fresh corn silks for oviposition, the damage to the developing ears is more general than damage to corn that is more mature. However, during dry, warm fall seasons

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[2]Entomologist, Bureau of Entomology and Plant Quarantine, U. S. Dept. of Agriculture; Associate Entomologist, Illinois Natural History Survey; and Associate Agronomist, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively. The writers express appreciation to J. M. Magner and A. F. Satterthwait for aid given in judging the corn.

considerable damage to the maturing corn may occur. Unpublished data taken by the authors have indicated that there is little correlation between resistance to early and to late damage. This discussion therefore will be confined to early damage, since in the tests reported upon late damage has been too light, as a whole, to serve as a basis for evaluating the strains.

Three methods of rating the amount of damage were studied, namely, (1) percentage of ears infested, (2) average degree of damage to individual ears, and (3) percentage of infested ears with damage extending more than ¾ inch from the ear tip. The last two methods were based on the division of the damage into the following five classes: Class 1, not exceeding five tip kernels destroyed or damaged; class 2, more than five kernels and not exceeding ¾ inch of the ear tip damaged; class 3, more than ¾ inch but not more than 1½ inches of the ear tip damaged; class 4, more than 1½ but not more than 2½ inches of the ear tip damaged; and class 5, all ears with damage extending more than 2½ inches from the ear tip.

It was found that the percentage of ears infested was high for all entries, with little difference among strains, and that therefore this method could not be used to express differential resistance. The percentage of infested ears with damage extending more than ¾ inch from the ear tip, or damaged more than class 2, seemed to be the most satisfactory method of measuring the differential resistance of the strains.

EXPERIMENTAL RESULTS

Damage by the corn ear worm to inbred lines with yellow endosperm is presented in Table 1. Four station-year records were obtained from 11 inbred lines, two and three station-year records from 21 lines, and one station-year records from 14 lines. Averages are shown for the 11 lines having four- station-year records.

Observations were confined largely to lines of most agronomic importance in the Corn Belt hybrid-corn program; hence, less important lines have been eliminated from time to time and new and more promising ones have been added.

Ear worm injury to inbred lines having white endosperm is shown in Table 2.

At Urbana in 1937 the percentage of infested ears damaged more than class 2 ranged from 0 for Ia. 701 to 90.5 for Kans. Kys, with an average of 36.5 for all entries. In 1938, the percentage ranged from 3.6 for U. S. 540 to 84.0 for Kan. K166, with an average of 36.8.

At McClure in 1938 the yellow inbred lines had from 0 to 98.0% of the infested ears damaged more than class 2. Inbred U. S. 4-8 showed the least damage and Kan. K166 was again the most severely damaged. In 1939, the damage ranged from 2.2% for Ia. 701 to 74.0% for U. S. 187-2, with an average of 27.7%.

Although considerable interannual variation existed for the inbred lines, some lines tended to be consistently resistant and others consistently susceptible. It is believed that some of the variation within inbreds may have been due to the fact that the lines consist of mixtures of homozygous types as a result of the seed having been carried in bulk even though the plants were self-pollinated each generation. It also may be possible that segregation is still occurring in some lines.

TABLE 1.—*Injury by the corn ear worm to various inbred lines of corn with yellow endosperm.*

Inbred line	Percentage of infested ears damaged more than class 2				
	Urbana		McClure		Average
	1937	1938	1938	1939	
Ia. 701	0.0	11.6	13.2	2.2	6.8
U. S. 540	23.0	3.6	13.2	2.9	10.7
Ill. R4	22.7	25.0	1.7	12.2	15.4
Ind. WF9	38.9	9.1	12.1	4.7	16.2
Ia. Pr	28.6	38.5	31.7	8.2	26.8
Ia. L317	36.4	45.0	5.6	26.7	28.4
Kans. K4	88.6	14.3	25.8	18.8	36.9
Ill. Hy	36.4	44.8	39.4	26.8	36.9
Ill. 5120	66.7	43.8	16.7	23.8	37.8
Kans. Kys	90.5	26.3	83.3	37.5	59.4
Ind. 38–11	82.1	73.1	78.7	61.9	74.0
Ill. A	4.0	40.0	—	—	—
Ind. 66	4.3	30.8	—	—	—
Oh. 51	14.7	32.4	—	49.5	—
Wis. CC6	15.4	—	—	—	—
Wis. CC2	16.7	—	—	—	—
Oh. 10	16.7	—	—	—	—
Ill. K	20.0	34.7	—	—	—
Ill. 5675	27.3	—	2.0	10.0	—
Ill. 2204	27.3	54.5	—	—	—
Ill. 2203	31.3	—	—	—	—
Ill. 4226	33.3	—	29.7	21.4	—
Ind. Tr	33.3	41.7	—	50.8	—
Ill. 4211	36.4	—	63.0	55.9	—
Ill. 90	38.7	30.4	—	20.0	—
Ind. L9	45.5	—	—	—	—
Ia. I198	51.9	—	—	—	—
Ill. 5676	61.6	—	—	—	—
Ill. 5679	66.7	—	—	53.3	—
Oh. 56	—	16.7	20.8	—	—
Ia. I205	—	21.7	33.3	—	—
Oh. 07	—	22.2	17.4	—	—
Ind. B2	—	41.9	33.3	—	—
Oh. 28	—	68.8	24.5	—	—
Kans. K166	—	84.0	98.0	—	—
U. S. 187–2	—	64.3	—	83.3	—
U. S. 7	—	—	—	2.7	—
U. S. 4–8	—	—	0.0	4.5	—
Tenn. J8–6	—	—	—	11.1	—
U. S. 2	—	—	—	11.4	—
Tenn. J7–2	—	—	—	13.3	—
U. S. 1	—	—	—	13.5	—
Ind. R94	—	—	—	14.8	—
U. S. 61R5	—	—	—	19.3	—
Oh. 02	—	—	66.7	21.9	—
Kan. K158	—	—	—	22.2	—
U. S. 6	—	—	—	23.7	—
Mo. R104C	—	—	—	30.0	—
Oh. 40B	—	—	—	34.0	—
U. S. 5	—	—	—	34.2	—
Ill. 5678	—	—	46.2	38.2	—
U. S. 11RA	—	—	—	58.8	—
Ind. P8	—	—	—	71.2	—
Average	36.5	36.8	32.9	27.7	31.8
Range	0–90.5	3.6–84.0	0–98.0	2.2–83.3	6.8–74.0

TABLE 2.—*Injury by the corn ear worm to various inbred lines of corn with white endosperm, McClure, Ill.*

Inbred line	Percentage of infested ears damaged more than class 2		
	1938	1939	Average
Ky. 27	10.2	8.5	9.4
Ind. 33-16	7.9	18.2	13.1
Ill. 5968	30.0	0.0	15.0
Ky. 39	40.6	45.9	43.3
Ky. 21	59.4	46.2	52.8
Mo. B103	76.9	71.4	74.2
U. S. 11a	—	4.7	—
Kans. PS4	—	5.9	—
U. S. 24	—	19.1	—
Ky. 2075	—	27.8	—
Kans. K22	—	32.4	—
Ky. 13	—	34.2	—
U. S. 11b	—	39.5	—
Kans. PS6	—	40.9	—
Ky. 50	—	40.9	—
Ky. 30A	—	57.7	—
Average	37.5	30.8	34.6
Range	7.9-76.9	0-71.4	9.4-74.2

The data show that some of the lines are uniformly resistant or susceptible in reaction at each of the different localities and under the somewhat variable population densities occurring in the tests.

The studies at McClure in 1939 included some inbred lines that had shown considerable differential resistance to ear worm damage in single-cross combinations at Arlington Experiment Farm, Va. in 1938.[3] One of these lines, U. S. 7, which had shown a high degree of resistance in single crosses at Arlington, continued to manifest this resistance at McClure when tested in the inbred condition. Likewise the inbreds U. S. 11RA and Ind. P8 that had transmitted susceptibility to single crossses in 1938 at Arlington continued to be highly susceptible as lines at McClure in 1939.

A considerable number of inbred lines have been tested in single crosses. The number of combinations in which any one inbred line was tested is, however, rather limited. In both 1938 and 1939, single crosses involving all possible combinations among the yellow lines Ia. L317, Ind. 38-11, Ill. Hy, U. S. 540, Ill. R4, and Ind. WF9 were tested. The results are shown in Table 3. In 1939, two additional groups of single crosses were tested. One group involved the yellow lines Ill. Hy, Oh. 40B, U. S. 4-8, Oh. 02, Ind. WF9, Ill. 90, and Oh. 51 and the other the white lines Ky. 27, Ind. 33-16, Ky. 21, U. S. 11a, Mo. B103, and Ill. 5968. The results from these tests are shown in Tables 4 and 5. Table 6 includes data on four to six single-cross combinations of 10 yellow inbred lines.

[3]The data on the ear worm reaction of these lines at Arlington, Va., were obtained by F. F. Dicke, of the Bureau of Entomology and Plant Quarantine and, M. T. Jenkins, of the Bureau of Plant Industry, U. S. Dept. of Agriculture.

TABLE 3.—*Ear worm injury shown by all possible single-cross hybrids of six yellow inbred lines of corn, McClure, Ill., two-year average, 1938–39.**

Inbred line	Percentage of infested ears damaged more than class 2					
	Ia. L317	Ind. 38–11	Ill. Hy	U. S. 540	Ill. R4	Ind. WF9
Ia. L317	—	17.2	10.1	2.6	1.4	4.9
Ind. 38–11	17.2	—	20.9	4.4	5.3	7.6
Ill. Hy	10.1	20.9	—	3.7	5.7	4.8
U. S. 540	2.6	4.4	3.7	—	2.4	3.4
Ill. R4	1.4	5.3	5.7	2.4	—	3.2
Ind. WF9	4.9	7.6	4.8	3.4	3.2	—
Average	7.2	11.1	9.0	3.3	3.6	4.8
Inbred line	16.2	70.3	33.1	8.1	7.0	8.4

*Seed of this group of crosses was obtained from G. H. Stringfield, Bureau of Plant Industry, U. S. Dept. Agriculture, Wooster, Ohio.

TABLE 4.—*Ear worm injury shown by all possible single-cross hybrids of seven yellow inbred lines of corn, McClure, Ill., 1939.**

Inbred line	Percentage of infested ears damaged more than class 2						
	Ill. Hy	Oh. 40B	U. S. 4–8	Oh. O2	Ind. WF9	Ill. 90	Oh. 51
Ill. Hy	—	8.9	10.8	32.4	9.6	12.4	12.9
Oh. 40B	8.9	—	11.2	28.6	5.8	4.4	13.2
U. S. 4–8	10.8	11.2	—	17.9	5.5	6.2	16.3
Oh. O2	32.4	28.6	17.9	—	14.4	5.1	30.5
Ind. WF9	9.6	5.8	5.5	14.4	—	2.9	9.8
Ill. 90	12.4	4.4	6.2	5.1	2.9	—	15.1
Oh. 51	12.9	13.2	16.3	30.5	9.8	15.1	—
Average	14.5	12.0	11.3	21.5	8.0	7.7	16.3
Inbred line	26.8	34.0	4.5	21.9	4.7	20.0	49.5

*Seed of this group of crosses was obtained from G. H. Stringfield, Bureau of Plant Industry, U. S. Dept. of Agriculture, Wooster, Ohio.

TABLE 5.—*Ear worm injury shown by all possible single-cross hybrids of six white inbred lines of corn, McClure, Ill., 1939.**

Inbred line	Percentage of infested ears damaged more than class 2					
	Ky. 27	Ind. 33–16	Ky. 21	U. S. 11a	Mo. B103	Ill. 5968
Ky. 27	—	0.0	2.3	0.6	6.8	0.5
Ind. 33–16	0.0	—	8.3	6.0	23.8	0.0
Ky. 21	2.3	8.3	—	6.7	22.9	2.2
U. S. 11a	0.6	6.0	6.7	—	21.1	0.6
Mo. B103	6.8	23.8	22.9	21.1	—	7.1
Ill. 5968	0.5	0.0	2.2	0.6	7.1	—
Average	2.0	7.6	8.5	7.0	16.3	2.1
Inbred line	8.5	18.2	46.2	4.7	71.4	0.0

*Seed of this group of crosses was obtained from W. H. Freeman, Illinois Agricultural Experiment Station, Urbana, Ill.

TABLE 6.—*Ear worm injury shown by various single crosses of ten yellow inbreds of corn, McClure, Ill., 1939.*

Inbred line	Percentage of infested ears damaged more than class 2				
	U. S. 2	U. S. 61R5	U. S. 6	U. S. 5	Inbred Line
Ind. P8	3.2	45.5	20.3	72.3	71.2
Tenn. J8–6	—	15.7	11.5	26.2	11.1
Kan. K158	—	5.0	3.6	10.6	22.2
Ind. R94	4.2	15.2	13.1	53.8	14.8
Mo. R104C	1.4	5.3	—	38.4	30.0
Tenn. J7–2	0.5	1.3	—	11.5	13.3
Average	2.0	14.7	12.1	35.5	—
Inbred line	11.4	19.3	23.7	34.2	—

Single crosses are, in general, less severely damaged by the ear worm than are inbred lines. The greater injury to the inbred lines appears to be the result of their smaller ear development, although it is probable that the increased resistance of the single crosses results from an accumulation of factors for resistance obtained from the two parents.

It would appear from the rather limited data presented that under conditions of moderate infestation some lines transmit a high degree of resistance even when combined in single crosses with susceptible lines, for example, U. S. 540, Ill. R4, and Ill. 5968. Crosses involving only resistant lines have for the most part been resistant. Variable results were obtained from the crosses involving a resistant and a susceptible line. As shown in Table 5, Ind. 33–16 × Mo. B103 is susceptible, although Ind. 33–16 is resistant as a line. When Ind. 33–16 was combined with Ky. 21, another susceptible line, the resulting single cross was moderately resistant. Mo. B103 transmitted susceptibility to three out of the five single crosses in which it occurred. Likewise, the combination of two susceptible inbreds resulted in a susceptible single cross. Although not included in the tables, an exception to this was observed in the case of a resistant hybrid resulting from the combination of the two susceptible lines Ind. 38–11 and Kan. Kys.

SUMMARY

The corn ear worm (*Heliothis armigera* Hbn.) injures field corn in the southern portion of the Corn Belt every year and throughout the Corn Belt in occasional years. The development and use of resistant hybrids seems to offer the most promising method of materially reducing ear worm damage to dent corn. The data presented in this paper deal with inbred lines and single-cross combinations grown in plots at three locations during the period of 1937 to 1939.

The data indicate that resistance to the corn ear worm is inherited. Some inbred lines tend to be consistently resistant whereas others are definitely susceptible.

Single crosses are, in general, less severely damaged than inbred lines.

Some inbred lines transmitted a high degree of resistance even when combined in single crosses with susceptible lines. Variability in results occurred with crosses involving a resistant and a susceptible line. The combination of two susceptible lines usually resulted in a susceptible single cross, but one case is cited where a resistant single cross resulted from such a combination.

Some inbred lines were stable in their resistance or susceptibility at the different localities included in this study.

LATTICE DESIGNS FOR WHEAT VARIETY TRIALS[1]

W. G. COCHRAN[2]

LATTICE designs were first described by Yates (8).[3] Their object is to provide a more accurate design than randomized blocks for varietal trials with a large number of varieties, while retaining as far as possible equal accuracy of comparison between every pair of varieties in the experiment. Although Goulden (3) recommended these designs for experiments on wheat varieties, so far they have not received an extensive trial in this country. In contacts with several wheat breeders who have used the designs, it appeared that the field operations presented no new difficulties; however, some questions were raised concerning the statistical analysis. It is hoped that a brief discussion of the nature of the designs and their analysis may be useful to those who contemplate using them. In particular, the method of adjusting yields will be considered in some detail, since this appears to be the least familiar feature.

To avoid confusion, it should be noted that lattice designs were called pseudo-factorial or quasi-factorial designs in the earlier papers on the subject. Further, the most accurate method of analyzing these designs was not discovered until some time after the designs were first published. Yates (9, 12) and Cox, *et al.* (2) present the new method of analysis.

METHODS OF REDUCING BLOCK SIZE

With experiments containing a large number of varieties, two devices have been used in attempting to obtain more accurate designs than randomized blocks. One is to insert a control variety at regular intervals within the block to serve as an indicator of soil fertility variations inside the block. The second is to reduce the block size, using blocks that do not contain all the varieties. The lattice designs belong to this class, and it may be instructive to examine their relation to earlier designs of the same type.

A well-known method is to divide the varieties into groups, inserting one or more common control varieties with each group, the groups being laid out in *separate* randomized blocks or Latin square experiments. This design provides accurate comparisons between varieties which are in the same group and is very convenient for making field observations since a control variety is always near at hand for comparison. It is much less satisfactory for comparing varieties in different groups, because no estimate of experimental error is available for the difference between the means of two such varieties. This difficulty can be overcome by comparing the varieties indirectly, calculating $(v_1 - c_1) - (v_2 - c_2)$, where c_1, c_2 are the means of the common control varieties in the two groups. However, these

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[3]Figures in parenthesis refer to "Literature Cited", p. 360.

comparisons have higher experimental errors than comparisons between varieties in the same group, an objectionable feature if all comparisons are wanted with equal accuracy. Moreover, the controls occupy a disproportionately large part of the experimental site.

Inter-group comparisons may be made directly, thus dispensing with the need for extra controls, by combining the separate experiments on the same site, as illustrated in Fig. 1a. Here the six groups are themselves arranged in a 6×3 randomized blocks design. The analogy with a split-plot design is evident. The analysis of variance of this design runs as follows:

	Degrees of freedom	Mean squares
Replications	2	
Between groups	5	
Inter-group error	10	a
Between varieties in the same group	30	
Intra-group error	60	b
Total	107	

Since there are three replicates, the error variance of the difference between two varietal means in the same group is $\frac{2}{3}$ b. For varieties in different groups, the corresponding error is a weighted mean of a and b, being in this case $\frac{2}{3}\left(\frac{5}{6} \text{ b} + \frac{1}{6} \text{ a}\right)$.

This design has many features in common with lattice designs. In particular, it utilizes both inter- and intra-group comparisons and requires no more land than randomized blocks from which it differs only in a rearrangement of the varieties within each replication. However, if the mean square *a* is much larger than *b*, indicating that the small blocks have been successful in avoiding soil heterogeneity within the replications, comparisons between varieties in different groups have a higher error than comparisons between varieties in the same group. The former are much more numerous than the latter. On the other hand, if a is about the same size as *b*, a randomized blocks design would have given about the same results. In fact, this design seems likely to prove more useful than randomized blocks only when comparisons within groups *are* required with higher accuracy, or when the number of groups is the same as the number of replications, permitting the use of a Latin square for inter-group comparisons.

Where all comparisons are desired with equal accuracy, the design above is at fault in keeping the same groups of varieties together in all replications, a pair of varieties either appearing *always* in the same group or *never* in the same group. It is clearly better to make the opposite rule, that a pair of varieties which are in the same group in the first replication shall not appear in the same group in any subsequent replication. This rule leads to the construction of lattice designs. Investigation was required to find whether designs obeying

this rule could be constructed. Where the number of varieties is an exact square, the first three replications can always be constructed by means of an auxiliary Latin square, as shown in Fig. 1b. Varieties in the same row of the square are put in the same group in replication 1, varieties in the same column in replication 2, and varieties having the same Latin letter in replication 3. With 36 varieties, no fourth replication of this type can be found, but one exists for all other squares from 16 up to 169, except 100.

Fig. 1a
Extension of split-plot design
Groups

IV	V	III	I	II	VI
22	27	14	2	7	34
21	30	15	3	8	36
24	25	16	6	9	31
19	29	18	5	12	33
20	26	13	4	11	35
23	28	17	1	10	32

III	IV	I	VI	V	II
13	21	4	35	27	9
14	19	3	33	26	10
18	24	6	36	29	11
17	23	1	32	30	12
16	22	2	34	28	8
15	20	5	31	25	7

II	I	IV	V	VI	III
11	2	21	30	31	14
12	1	19	28	35	16
7	6	22	25	34	18
9	5	23	27	36	15
10	3	24	26	32	13
8	4	20	29	33	17

Design: 36 varieties in 3-fold replication

The numbers 1–36 denote varieties

Fig. 1b
Lattice design in three replications
(Before randomization)

1	7	13	19	25	31
2	8	14	20	26	32
3	9	15	21	27	33
4	10	16	22	28	34
5	11	17	23	29	35
6	12	18	24	30	36

1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24
25	26	27	28	29	30
31	32	33	34	35	36

1	2	3	4	5	6
10	9	7	11	12	8
17	18	14	15	16	13
20	19	23	24	21	22
27	28	30	25	26	29
36	35	34	32	31	33

Auxiliary
Latin Square

1A	2B	3C	4D	5E	6F
7C	8F	9B	10A	11D	12E
13F	14C	15D	16E	17A	18B
19B	20A	21E	22F	23C	24D
25D	26E	27A	28B	29F	30C
31E	32D	33F	34C	35B	36A

Fig. 1.—Comparison of "split-plot" design and lattice design.

COMPARISON OF LATTICE DESIGNS AND RANDOMIZED BLOCKS

FIELD OPERATIONS

There is no single measure of the relative merits of two designs. However, probably the most important aim in experimental design is to obtain a given degree of accuracy at the least cost. As regards cost of field operations, the lattice designs, like the split-plot designs,

differ from randomized blocks only in a different grouping of the varieties within each replication. Thus the cost of field operations is the same for both designs, the principal difficulty common to both being that of harvesting when the varieties mature at different times. In one respect the lattice designs are more flexible under field conditions, as Goulden (3) has pointed out. If the experiment is laid out in an irregularly shaped field, or portion of a field, it may be difficult to plan the design so that each replication is compact. The accuracy of a randomized blocks design may suffer considerably under such conditions. However, if the *small* blocks are kept compact, which is usually easy, only the inter-block comparisons in the lattice design are affected by the manner in which the small blocks are grouped to form a replication. Since the inter-block comparisons contribute only a small fraction of the total information, the accuracy of lattice designs suffers much less in these circumstances.

These remarks were strikingly illustrated on Wiebe's (7) wheat uniformity trial which appears to provide the only wheat data in the literature copious enough to test designs for many varieties. A design for 81 varieties in three replications was superimposed on the data, the plots being three rows (3 feet) $\times$ 15 feet, with only the centre row harvested. Using exactly the same plots and site, a "good" and a "bad" grouping of the plots into replications were examined. For randomized blocks, the standard errors of a varietal mean were 8.0% and 10.4% in the two cases. For the lattice design, the errors were 6.60% and 6.63%.

NUMBERS OF VARIETIES AND REPLICATIONS

While randomized blocks designs can be constructed for any number of varieties, the lattice designs are more restricted in this respect. The type described above exists only when the number of varieties is an exact square, of which the most useful are those from 25 to 169. With numbers in this group other than 36, 100, and 144, any number of replications may be constructed until every variety has appeared once with every other variety in the same block, this requiring $(n + 1)$ replications for n^2 varieties. With 36 or 100 varieties, four and six replications may be secured by duplicating the designs for two and three replications, respectively. So far as the writer is aware, the 12×12 design has been constructed only up to four replicates and requires the same device to obtain six replicates. In fact, this device may also be used for the other numbers of varieties, with a slight loss in accuracy but some compensation in simplicity of analysis.

When the number of varieties is the product of two approximately equal numbers, e.g., 72 or 90 varieties, similar designs are available for an even number of replications (Yates, 8). These, however, require a slightly more elaborate analysis.

STATISTICAL ANALYSIS

Since field operations are essentially the same for both designs, their relative efficiency depends primarily on the labor involved in

the statistical analysis and on the accuracy attained with a given number of replications. While the complete analysis of the lattice designs is more complicated than that of randomized blocks, the former possess the useful property that they can be analyzed alternatively as an ordinary randomized blocks experiment. This statement implies two things, *viz.*, (a) the error mean square found by the usual randomized blocks analysis is an unbiased error with which to compare the varieties mean square, and (b) what is more important, this error may safely be used to test the difference between any pair of varietal means. Of course, the *true* error is not exactly the same for all pairs of varieties, since by the nature of the design some pairs occur more closely together than others. However, the same phenomenon occurs in randomized blocks, as can be seen by examining any design after it has been randomized.

Investigation by Yates (9) showed that the use of a common error was about equally valid in the two designs. It may be noted that the first property above also holds for the "split-plot" design previously discussed, but the disparity in the true errors for different pairs of varieties is usually too great for the second property to hold.

This property of lattice designs is valuable in many cases. Where a rapid preliminary inspection of the results is wanted, the randomized blocks analysis may first be calculated. Little labor is wasted by doing so even if it is intended later to complete the full lattice analysis, since all calculations already made for the randomized blocks analysis are required in the full analysis. Further, a randomized blocks analysis is adequate for any field measurements which are little affected by soil fertility variations.

The extra numerical work in the full lattice analysis consists in calculating the sum of squares between blocks and adjusting the varietal means. Practically all the extra operations are simple additions which are self-checking. The times required for the two types of analyses were compared for a lattice design with 81 varieties and four replications formed by duplicating the design for two replications. The machine used was an electric Monroe without automatic multiplication or division. With no mistakes in computation, it took 2 hours 45 minutes to form the varietal totals and the randomized blocks analysis of variance, with checks by re-computation where necessary. The lattice analysis leading to the adjusted varietal totals required 4 hours 30 minutes. In the latter, it is easier to locate mistakes in addition, since more sub-totals and subsidiary checks are available. Of course, with someone unfamiliar with the lattice design, much more time would be consumed at a first trial.

NATURE OF THE ADJUSTMENTS

Extra complication in the statistical analysis may be a drawback to the widespread use of a design in other respects. If the experimenter does not clearly understand the assumptions involved in the statistical manipulations, or the reasons for them, he loses confidence in the final results of the calculations. The principal difference between the randomized blocks analysis and the lattice analysis is that

the ordinary varietal mean yields are adjusted in the latter to what is considered a more accurate estimate. Examining the nature of the adjustment in some detail in the hope of clarifying its common-sense interpretation, the lattice design with two replications is chosen for simplicity, the nature of the adjustment being essentially the same for all lattice designs. The formula for adjusting the mean yield of a typical variety v reads as follows:

$$\text{Adjusted yield} = \text{unadjusted yield} - \left(1 - \frac{E}{B}\right)(M_B - M_V) \qquad 1$$

where E = error mean square, B = blocks mean square
M_B = mean yield of the small blocks containing v,
M_V = mean yield, in the rest of the experiment, of the varieties appearing in those blocks.

The adjustment is the product of two factors. Consider the second factor. With two replications, every variety occurs in two of the small blocks, but no two varieties appear in the same pair of small blocks. Thus, in taking the unweighted mean, a variety which happens to be grown in a pair of good blocks is favored, and one which is grown in a pair of poor blocks is handicapped. The lattice analysis endeavors to eliminate this source of error from the varietal comparisons. In order to correct varietal means for block differences, we must have an estimate of the relative fertility of the different pairs of blocks. At first sight, it might seem sufficient to calculate the difference between the mean yield of any pair of blocks and the mean yield of the whole experiment. This is not satisfactory, however, since different blocks contain different varieties. The best available estimate is obtained by taking the mean yield of the blocks minus the mean yield *in the rest of the experiment* of those varieties which appear in the blocks. On inspecting the design, it will be found that the latter mean yield contains one plot from every block in the experiment, so that the comparison is a fair one. To make the adjustment, the above quantity must, of course, be *subtracted* from the mean yield of a variety.

The adjustments described in the preceding paragraph are based on the assumption that there *are* real differences in fertility between blocks. However, in an experiment where there are no such differences, yields adjusted by this method are less accurate than unadjusted yields, because the adjustments perform no useful purpose, merely adding to the experimental error of the mean yields. Thus it would be unwise to apply the method of adjustment automatically in all experiments. Further examination of the differences between blocks showed that the most accurate estimates of mean yield were obtained by reducing the adjustments to $\left(1 - \frac{E}{B}\right)$ of their full value. The factor $\left(1 - \frac{E}{B}\right)$ reduces to zero (no adjustment) when B is no larger than E, i.e., when there are no real differences between blocks. The factor approaches unity (full adjustment) only when E/B is

very small, i.e., when differences between blocks are large. In intermediate cases, the partially adjusted yields, as Yates (10) has called them, are more accurate than either the fully adjusted yields or the unadjusted yields.

Agronomists may feel some diffidence in adjusting the yield of a variety by using the performance of other varieties which happen to appear with it in the same block, since some varieties may be accompanied by high-yielding varieties and some by low-yielding varieties. However, it should be noted that the adjustment does not depend on the average yields of the varieties which are associated with a given variety. The addition of say, 100, to all the plots of a given variety leaves the blocks and error mean squares unaltered, while if this variety appears in the second factor, the plus and minus terms are increased to exactly the same extent. There is the further point that different varieties may not respond in the same way to variations in the fertility of the blocks. This may have been the reason for the statement by Weiss and Cox (6) quoted by Salmon (5), that, "The partial confounding of variety differences with block effects makes it unwise to employ this type of design when comparing varieties which have an extremely large range in yields".[4] However, Weiss and Cox used an earlier method of analysis in which the full adjustments were made, the factor $\left(1 - \frac{E}{B}\right)$ being set equal to unity. With the type of adjustment made in equation 1 above, the possible danger from this source is much smaller, for if different varieties do not respond in the same way to the variations in fertility from block to block, the blocks mean square will tend to be no larger than the error mean square, and the lattice analysis will automatically lead to unadjusted, or only slightly adjusted yields. In fact, there is no danger in using the lattice *design* instead of randomized blocks, since the results can be analyzed as randomized blocks if certain varieties give such poor yields that it is considered unsafe to use them to adjust the yields of good varieties.

MISSING PLOTS AND VARIETIES

In trials with many varieties it is frequently necessary to analyze the results of experiments in which several plot yields, or the entire yields from several varieties, are missing. The randomized blocks analysis is extremely useful in dealing with such cases. The formulae for the estimation of missing values are fairly simple, while any number of varieties may be omitted from the analysis without any additional complications in the numerical work.

Where it is desired to use the lattice analysis, formulae for the estimation of missing plots have been given by Cornish (1). These formulae are appropriate to the earlier method of analysis in which the *full* adjustments for block differences were made. The corresponding formulae for partially-adjusted yields are at present being in-

[4]This statement referred to the incomplete randomized blocks design which differs somewhat from lattice designs. However, the authors later apply a similar warning to the lattice square designs.

vestigated by Cornish. It seems unlikely that much change will be necessary if the blocks mean square is appreciably above the error mean square.

No publication has yet appeared explaining how to make the full lattice analysis when several varieties are missing. From preliminary inspection of the problem, it appears that the calculations will become considerably more complicated. Further investigation is needed to set up a methodical method of computation and to consider in what circumstances the extra computational labor is justified.

RELATIVE ACCURACY OF COMPARISONS BETWEEN VARIETIES

It is usually safe in the lattice analysis to use a common standard error for all comparisons between pairs of varieties. Strictly speaking, two standard errors are required, one for a pair of varieties which do not appear in the same block, and one, slightly lower, for a pair which appear in the same block. However, even with only two replications—the most extreme case—the ratio of the former to the latter standard error does not exceed $\sqrt{\frac{p+2}{p+1}}$, where p^2 is the number of varieties, and approaches this limit only when the differences between small blocks are large. Separate standard errors should first be calculated for the two types of comparison before deciding whether to use a common error.

Sometimes the experimenter may wish to replicate a standard variety more frequently than the new varieties, either to secure more accurate comparisons between the latter and the standard or to assist in taking field notes. In the lattice designs, this extra replication may be secured simply by choosing two or more of the p^2 varieties to be a common control variety. While the controls should be randomized in the same way as the new varieties, the field plan can usually be arranged so that two controls never appear in the same block, thus giving a more even distribution of the controls through each replication. In analyzing the results, it is simplest to regard the controls at first as separate varieties, so that the usual method of analysis applies. The average of the controls should be taken when the adjusted mean yields have been computed, the standard error of this average being, of course, $1/\sqrt{r}$ times the standard error of a single varietal mean, where r is the number of controls averaged.

COMPARISON OF RESULTS FROM DIFFERENT YEARS OR DIFFERENT CENTRES

In most breeding programs, promising varieties are tested in several different localities and over several seasons. A combined analysis may be wanted to discover those varieties which are consistently superior and those which are specially adapted for certain localities. Even with the simplest of designs, a satisfactory analysis is more difficult than is usually realized (cf. Yates and Cochran, 11). In particular, special methods are necessary if the experimental errors differ widely from experiment to experiment.

With lattice designs, the only additional complication arises from the slight inequality mentioned above in the relative accuracy of comparisons between different pairs of varieties. If the same design (apart from the randomization) is used at a number of places, little error is introduced by calculating the interaction of varieties with places in the usual way, using adjusted totals or means.

GAIN IN ACCURACY

Information is obtained on the relative accuracy of randomized blocks and lattice designs with the same number of replications (a) by superimposing both designs on uniformity-trial data and (b) by analyzing lattice experiments both by the lattice analysis and by the randomized blocks analysis. To make a fair comparison, each design should be laid out in what is considered from previous experience the most accurate arrangement on the particular site used. This condition can be fulfilled with uniformity-trial data, but in a lattice experiment, where the shape of the replication is fixed when the lattice is laid down, we must consider whether the same shape would have been used had the experiment originally been planned as randomized blocks. As a rule, this should be so, because the optimum shape of replication for the lattice is usually also the optimum for randomized blocks.

The measure adopted for the statistical accuracy of a design is the inverse of the average variance of the difference between two varietal means. For the relative accuracy (or efficiency) of two designs, we use the inverse ratio of these variances. Variances are used instead of standard errors because the variance of the mean of r replications is $1/r$ times the variance of a single replication. Thus if the lattice design in two replications has an efficiency of 1.5 (150%) relative to randomized blocks, this implies that a randomized blocks design with three replications would have given about the same accuracy as the lattice design with two replications.

Information on wheat is scanty. Of six experiments carried out by Dr. L. R. Waldron, with numbers of varieties ranging from 49 to 169, two showed no gain, one a negligible gain (2%), while the other three showed gains of 39, 45, and 156%.[5] With 36 varieties, Goulden (4) obtained increases of about 70 and 90% on Wiebe's data. For other crops for which comparisons are available, principally corn, the average gain appears to be about 30%. With this figure, a lattice design in three replicates is almost as accurate as a randomized blocks design in four replicates. Valuable information can be obtained by calculating the relative efficiency as a routine matter whenever lattice designs are used which provide a fair comparison. If the experiences of different workers are pooled, it should be possible to assess the usefulness of these designs for wheat trials in a short time. Results of a similar investigation on corn will be published shortly, covering over 70 lattice experiments carried out or supervised by the Iowa Experiment Station.

[5]The writer is indebted to Dr. Waldron for permission to use his results in calculating these gains.

OTHER LATTICE DESIGNS

If a higher degree of replication is desired, it may be possible to use lattice designs in which *every* pair of varieties occurs once in the same block. For 25, 49, 64, 81, and 121 varieties, these designs require 6, 8, 9, 10, and 12 replications, respectively.

Certain lattice designs can be laid out in Latin squares. For 25, 49, 81, and 121 varieties, 3, 4, 5, and 6 replications are required, respectively. For 64 varieties, 9 replications are required, while no design exists for 36 and 100 varieties. The writer does not possess the data necessary to give an opinion on the advisability of Latin square designs for wheat, where the plots are usually 1 rod long and one, two, or three rows wide. Where experimenters have found ordinary Latin squares superior to randomized blocks in small varietal trials, the same result would be expected to hold with lattice designs. On Wiebe's data, lattice designs arranged in Latin squares proved substantially more accurate than lattice designs arranged in small blocks, but this result may not be typical.

For numbers of varieties over 200, cubic lattice designs arrange p^3 varieties in blocks of size p (9). The number of replications must be a multiple of three.

Goulden (3) also recommends the *incomplete randomized blocks designs* in which the number of varieties need not be a complete square. However, these designs cannot as a rule be arranged in separate replications or analyzed alternatively by the randomized blocks analysis.

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AN ASSOCIATION OF SMOOTH-AWNEDNESS AND SPRING GROWTH HABIT IN BARLEY STRAINS[1]

G. K. MIDDLETON AND W. H. CHAPMAN[2]

ROUGH-AWNED strains of barley have consistently outyielded both hooded and smooth-awned types in fall-sown nursery trials conducted at the Piedmont Branch Experiment Station, Statesville, N. C. The relatively low yields of hooded as compared with awned strains have been observed by a number of investigators, and an explanation of this difference has been offered by Harlan and Anthony (2)[3] based upon certain physiological functions of the awn.

As regards smooth- and rough-awned types, the only results which have been reported, with which the writers are familiar, are those by Harlan, Martini, and Stevens (4). These investigators, working at Aberdeen, Idaho, found smooth-awned selections from a composite hybrid to produce lower yields on the average than rough-awned ones, but did not offer a full explanation of this phenomenon. They found, however, that on the average the smooth-awned forms were a few days earlier in heading than the rough-awned sorts, that they were seemingly more sensitive to a frost that occurred during the heading period, and that they averaged greater floret sterility.

This publication presents the results of certain census studies made on this same composite when grown from fall seedings, and of yield trials with the bulked segregates separated during the course of this study. Results secured with true-breeding segregates from a single cross are also given and show an association between smooth-awnedness and spring growth habit which may explain in part the difference in yielding ability of the two types.

RESULTS WITH THE COMPOSITE

In the fall of 1929, a small quantity of seed of composite hybrid No. C. I. 5461 was received from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and seeded at Statesville, N. C. This composite has been described by Harlan and Martini (3), who state that 28 varieties were used in its preparation and that all but one of the possible hybrid combinations were made between these varieties. The parent varieties may be classified as follows: Six-row rough-awned, 17; two-row rough, 7; six-row smooth, 3; and 6-row hooded, 1.

WINTER SURVIVAL DATA

A small plot of this composite has been grown each year since the seed was first received. In the spring of 1936, a plant census was taken

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[2]Agronomist and Assistant Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 366.

to determine what types were predominating. For this study the equivalent of 20 16-foot rows was harvested and classified by head type into five groups. These groups included the four listed above and an additional group for two-row smooth-awned plants. This study showed that the smooth-awned and hooded types had disappeared to such an extent that it was decided to start the experiment over and make an annual census. A supply of F_3 seed from the original source, kept in cold storage since 1929 by the Division of Cereal Crops and Diseases, was secured in 1937 and planted, part at Statesville and part at the Mountain Branch Experiment Station at Swannanoa, N.C. A germination test of this stored seed showed it to be approximately 85% viable. It is possible that certain types had disappeared more than others, but the percentages obtained in the 1938 census were fairly comparable to the expected, and especially at Statesville where there was apparently no winterkilling that year.

Each spring part of the material was cut and threshed in bulk for planting and part of it classified according to head type. For classification purposes, all the material from 10 16-foot rows was used in 1938 and 1939, while in 1940 only one-half of this amount of material was used. The results are presented in Table 1.

TABLE 1.—*Showing winter survival of different types of barley in composite hybrid No. C. I. 5461 at Swannanoa and Statesville, N. C.*

Year seed received	Year census taken	Generation	Total No. heads classified	Percentage falling in different types				
				6-row rough	6-row hooded	6-row smooth	2-row rough	2-row smooth
			Swannanoa, N. C.					
1937	1938	F_3	2,899	60.9	5.1	6.8	23.8	3.4
	1939	F_4	2,162	69.8	5.7	3.3	20.6	0.6
	1940	F_5	1,433	72.4	8.3	0.4	18.8	0.1
			Statesville, N. C.					
1937	1938	F_3	3,214	62.9	4.1	9.9	19.7	3.4
	1939	F_4	2,457	79.5	2.7	6.9	9.4	1.5
	1940	F_5	1,675	85.4	2.2	2.5	8.2	1.7
1929	1936	F_9	5,088	75.7	3.7	1.1	17.9	1.6
	1938	F_{11}	3,525	73.1	2.0	0.4	22.8	1.7
	1939	F_{12}	3,385	80.5	1.9	0.5	15.8	1.3
	1940	F_{13}	1,196	89.5	0.3	0.3	8.8	1.1

The results show the smooth-awned types to be rather rapidly disappearing at both stations, though possibly somewhat faster at Swannanoa than at Statesville. The hooded types are also disappearing at Statesville, but at the Mountain Station they have not shown a decrease between the third and fifth generation. It is probably too early to state that this relative difference in survival of hooded types between Statesville and Swannanoa will persist, but it is quite possible that it will. In the case of the smooth-awned segregates,

however, there seems to be no question but that they are disappearing at both stations.

In addition to winter survival data, further evidence of differences in adaptation of the rough- and smooth-awned types is found in the results of yield trials at Statesville with bulked segregates.

YIELD TRIALS WITH BULKED SEGREGATES

After making the first census in 1936, each of the five groups of plants were threshed and the bulked seed used in comparative yield trials. The tests were conducted in duplicate single-row, 16-foot plots in 1936–37 and in three-row plots during the two following years, with three replications in 1937–38 and five in 1938–39. The five types were arranged systematically in the different replications. The results are presented in Table 2.

TABLE 2.—*Showing comparative yields of bulked segregates of five types of barley separated from composite hybrid C. I. No. 5461 after being grown in bulk from 1929–1936 at Statesville, N. C.*

Type	Yield in bushels per acre				Odds*
	1937	1938	1939	Average	
6-row rough........	29.8	38.5	57.4	41.83	——
6-row smooth.......	21.8	36.5	39.6	32.62	9.7:1
6-row hooded.......	21.2	31.5	53.7	35.47	41.6:1
2-row rough........	25.5	42.3	45.3	37.70	3.9:1
2-row smooth......	20.0	35.3	53.8	36.37	14.9:1

*Comparison of 6-row rough group with each of other types.

An analysis of the data, using Student's method (5), shows a significant difference between the yield of the six-row rough and six-row hooded types, but odds which are too low for significance between the six-row rough and either of the smooth-awned groups. If, however, the average yield of the two rough-awned groups is compared with that of the two smooth-awned groups, a highly significant difference is obtained, with odds of more than 99:1. If, on the other hand, the data are grouped according to six-row and two-row types, there is no difference in yield. By the first method of grouping, we have average yields of 39.8 and 34.5 bushels for the rough- and smooth-awned groups and by the second method, 37.3 and 37.0 bushels for the six-row and two-row groups, respectively.

RESULTS WITH A ROUGH × SMOOTH-AWNED CROSS

In 1936, a cross was made between rough- and smooth-awned selections from this composite which has given very interesting results. Selection 15 is a six-row rough-awned type with white lemma and selection 52–1 a six-row smooth-awned, black barley. The latter is similar to Lion, one of the three smooth-awned varieties used in the preparation of the composite. In F_2 there was a very good two-factor segregation for color of lemma and roughness of awn. Measurements

taken on the F_2 plants gave a slightly higher value for yield of seed in grams and number of culms per plant for the rough than for the smooth-awned types, but the differences were not significant.

SURVIVAL AND YIELD OF F_3 LINES

In the fall of 1938, 25 seed from each F_2 plant from this cross were spaced in a 5-foot row at Statesville and a similar planting made at Swannanoa. Stand counts made both in the fall and in the spring at Statesville and in the spring at Swannanoa showed no differences in survival of the two types that year. There were, however, yield differences between the true-breeding segregates which were significant, as shown in Table 3.

TABLE 3.—*Showing the comparative yield of true-breeding rough- and smooth-awned segregates in a barley cross, selection 15 × selection 52–1, in grams per 5-foot row with standard error.*

Type of awn	No. of lines	Location of test	
		Statesville	Swannanoa
Rough	33	169.8 ± 8.03	100.5 ± 12.8
Smooth	34	111.3 ± 6.21	64.5 ± 9.2
Difference		58.5 ± 10.15	36.0 ± 15.76

SMOOTH AWN AND SPRING GROWTH HABIT

While no differences were found in the survival of these types during this year, it was observed during the winter that the smooth-awned segregates had made the most fall growth, indicating the possibility of an association between this factor and growth habit. Heading notes taken the following spring on April 7, 10, 12, and 14 showed the smooth-awned families to come into head 2 to 3 days earlier, on the average, than the rough-awned families. These findings are not in agreement with those of Griffee (1) who, working with a cross of Svanhals × Lion, found no association between date of heading and type of awn, but they do agree with the results of Harlan, Martini, and Stevens (4).

Thinking that if there was an association between these factors it would be brought out more clearly from spring than from fall sowing, seed from the F_3 of these same families were planted at Swannanoa on March 21, 1940, and heading notes taken on June 20. The results are given in Table 4.

The data show a very clear relationship between spring growth habit and smoothness of awn. This was still noticeable on July 19 when it was observed that 29 of the 33 rough-awned families were still not fully headed as compared to only 5 of the 34 smooth-awned families. The parents were not grown with this material, but were grown in the spring of 1939 when a similar difference was noted between them. Seeded on March 20, 1939, selection 52–1 was completely

headed on July 19, while only 74.7% of the plants of selection 15 had produced any heads.

TABLE 4.—*Showing an association between factors for smooth awn and spring growth habit in a barley cross, selection 15 × selection 52–1, at Swannanoa, N. C., June 20, 1940.*

Type of awn	No. lines	No. of lines headed to different degrees			
		100%	99–50%	49–25%	Under 25%
Rough	33	1	14	7	11
Smooth	34	22	10	2	0

DISCUSSION

In presenting the above evidence of an association between factors for smooth awnedness and spring growth habit, it is not claimed that this is the only factor affecting the adaptation of smooth-awned strains when fall sown. No data were taken on sterility or number of seed produced by individual rough- and smooth-awned plants, either of which might conceivably be a factor affecting the yield of the two types; or affecting survival in the composite. It does seem, however, that the growth habit of the smooth-awned types has played a definite part in their lack of adaptation.

Close observation of other material has added to the evidence. In the fall of 1939, all smooth-awned lines from three crosses, including the cross of selection 15 × selection 52–1, were planted for the purpose of isolating promising lines to be used in yield trials the following year. All of these made considerable fall growth and were injured by early freezes to such an extent that none were harvested the following spring.

A comparison of the F_3 and F_{11} composite material in December 1937 showed the former to contain a mixture of types so far as growth habit is concerned, while the older material was made up largely of plants with a very prostrate growth habit.

These evidences, together with the data presented, strongly support the theory that the spring growth habit of the smooth-awned lines is one important factor in their lack of adaptation in fall-sown trials.

SUMMARY

Results of census studies made on a barley composite hybrid, No. C. I. 5461, between the third and thirteenth generations and yield trials with bulked segregates from this composite are reported; also results with true-breeding segregates from a single cross between rough- and smooth-awned strains. The data show the following:

1. Smooth-awned types have rapidly disappeared from the composite both at Statesville and Swannanoa, N. C., and hooded types at the former station.
2. Yield trials conducted for 3 years with bulked segregates gave results significantly in favor of rough-awned forms as compared with either smooth-awned or hooded sorts.

3. Yield trials with true-breeding lines from the single cross were also significantly in favor of the rough-awned types.
4. An association was found to exist between factors for spring growth habit and smooth awnedness. This association is offered as one factor in the lack of adaptation generally observed in smooth-awned strains when fall-sown at Statesville and Swannanoa.

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NOTES

SODIUM FLUORIDE AS AN HERBICIDE

IN 1925, a tobacco patch was dusted with sodium fluosilicate to test the insecticidal properties of fluorides. The tobacco suffered no foliage injury, but smartweed growing around the borders was observed to be badly injured. This selective action of sodium silicofluoride for smartweed was striking. Since then other weeds have been found susceptible to fluoride injury, particularly annuals.

In the summer of 1940, sodium fluoride was given a trial for the control of crabgrass in lawns. A 2% solution killed the weed or injured it severely. Crabgrass was found to be difficult to wet. Water literally rolled off the plants as off a duck's back. A 1% solution of soap decreased the surface tension of the liquid and resulted in the wetting of the crabgrass. The combination of 2% sodium fluoride and 1% soap powder gave good control of crabgrass without causing permanent injury to bluegrass. Some browning of the bluegrass occurred, but growth was resumed with the first good rains. The control obtained with 2% sodium fluoride was as good as with "Sinox",[1] which is highly recommended for crabgrass. The fluoride, moreover, is much cheaper, more convenient to handle, and easy to apply.

In California, wild mustard and wild radish are two serious annual weeds. Results of trials of sodium fluoride suggest that it may offer promise as an herbicide against these plants. Other weeds doubtless would be highly susceptible to control by sodium fluoride. Only extensive trials in various parts of the United States will establish the possible usefulness of sodium fluoride for weed-killing purposes.

Perennials do not seem to be easily injured by sodium fluoride. Quick-growing, succulent annuals with thin cuticle are most susceptible. There appears to be wide variation in the effects of this chemical on different plants. Some plants, notably oxalis, sheep sorrell, persimmon, scrub pine, colias, smartweed, and crabgrass, are easily injured. Others, such as red cedar, hickory, Russian olive, and holly, can withstand a saturated solution of 4% sodium fluoride with little or no injury.

A large number of factors are involved in the cause of injury. There appears to be no correlation as to calcium content. The stage of growth or succulence seem to be important. Early in the season, when the foliage was tender, black gum was injured by a 1–4,000 solution on June 18, whereas on July 26, a 1–500 solution produced little or no injury. It appears that with the progress of the season, the cuticle becomes thickened, especially in dry weather. For best results, the sodium fluoride should be used early in the season, while the plants are tender and the cuticle is thin and permeable.—S. MARCOVITCH, *Tennessee Agr. Exp. Station, Knoxville, Tenn.*

[1]WESTGATE, W. A. and RAYNOR, R. N. A new selective spray for the control of certain weeds. Calif. Agr. Exp. Sta. Bul. 634. 1940.

A METHOD OF FORMING A PERMANENT PEDIGREE RECORD FOR BREEDING STRAINS OF SUGAR BEETS

EVERY plant breeder attempting to produce new strains of sugar beets, commonly referred to as "varieties," has been confronted with the problem of keeping a record of the pedigree of the various strains. A method which is permanent inasmuch as the yearly additions could be made without necessitating revision or copying the entire pedigree would be desirable. The method described here has been used for the past three years and has proved to be very satisfactory.

A modification of the numbering scheme developed by members of the Division of Sugar Plants of the U. S. Dept. of Agriculture, which we have been using, will serve to illustrate the method. Each lot of seed is designated by a seed number. The first figure of the seed number is the last figure for the year the seed was produced. The second figure is a zero. This second figure represents a 10-year series, and at the end of 10 years the zero may be replaced by a dash or other designations. Each planting of beets for seed is assigned a location number, starting with the number 1 and numbered consecutively, each year. This location number enters into the seed number designating that particular crop of seed and follows the year and series figures. The balance of the seed number for any particular lot of seed is determined by the breeding technic employed in the development of that seed. The following outline briefly describes the complete numbering scheme:

80319.	Seed of a space-isolated individual root.
80319–0.	Seed of a space-isolated group of roots of the same variety.
80319–5.	Open-pollinated seed of plant number 5 within a group of roots of the same variety.
80319–C8.	Inbred seed formed by bagging plant number 8 of a planting of more than one variety.
80319–00.	Pooled seed of a space-isolated cross of two or more varieties.
80319–02.	Seed produced by variety number 2 of a cross of two or more varieties.
80319–007.	Open-pollinated seed of plant number 7 within a cross.
80319–00C2.	Hybrid seed produced by confining two varieties in a bag forming cross No. 2.
80319–0C5.	Inbred seed formed by bagging plant number 5 of a group planting of the same variety.

The 80 refers to the year 193(8) and the 10-year series (0). In 1941 this may become 1–. The number (319) following the 80 represents the location number of the planting.

For the pedigree record, cards (Fig. 1) were obtained from a local printing shop. The cards are 4½ inches high with ½ by 1¼ inch tabs making the total height 5 inches, and are 12 inches wide. The tabs are arranged in 10 positions. The cards were cut from sheets 25 × 30 inches of 140-pound substance of Darien index paper in such a manner that the grain of the paper is vertical when the card is in

place in the file. This grade material may be rolled in the typewriter without bad effect and all records may be typed if desired. The first position on the left is used to designate the source. Since the chief source of breeding material is commercial strains or commercial brands, it will be necessary to abbreviate most of these names. The abbreviated name is placed on the tab of a card having the first position on the left and these cards are filed in alphabetical order. The body of the card is used for notations in regard to this material (Fig. 1, "Cesena" card). The second position cards will be used for the first year's progeny. Each position thereafter will represent one year's progeny.

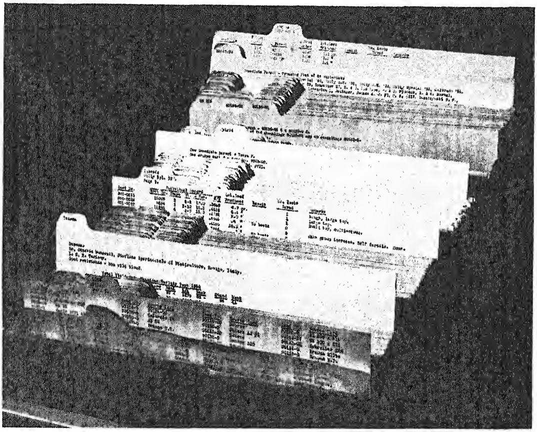

FIG. 1.—A card file forming a permanent pedigree record for breeding strains of sugar beets.

The file will grow one position each year for 10 years. At the end of 10 years each strain on hand will be assigned a source card and all information of value may be placed on the body of the card and thus a new 10-year file is started. Each year when the cards for that year's progeny are made up, the seed number is placed on the tab for the position required for that year (with the exception of pooled seed arising from crosses). The immediate parent and whatever information is desired is placed on the body of the card. The immediate parent should always be on the card so that in case the cards become misplaced they can readily be placed in order. These cards are placed in the file *immediately in front of their respective immediate mother parent.*

In the case of crosses where the seed is pooled all information in regard to this strain is placed on a source card with the seed number placed on the tab. These cards are placed at the rear of the other source cards and arranged in numerical order (Fig. 1, "80267–00"). In addition, cards for that year's position are also filled out with the word "hybrid" on the tab and filed in the proper position in front of each immediate parent in order that this strain may be represented among the progenies of each immediate parent (Fig. 1. "Hybrid"). All progeny arising from this cross is placed on cards in their regular position, using the source card for the cross as the mother parent. Thus, there may be a source card with no progeny cards preceding it until, say the sixth position. The same would be true of selections from the same source in later years.

Where the crosses are harvested separately by mother parent, the data for each strain are placed on a card of that year's position and each card filed immediately in front of the immediate mother parent. In the case of inbreds arising from bags, since these may be numerous for any given strain, the word "inbred" and the mother parent name or number is placed on the tab of a card of that year's position. The data regarding all of the inbreds from that parent for that year are placed on this card in order by seed number, one inbred to each line. As many cards as necessary may be used by assigning page numbers to them (Fig. 1, "Inbreds"). Bag hybrids may be handled similarly (Fig. 1, "Hybrids").

If this method of filing is followed, then by opening the file to a card giving the strain in which one is interested, the entire pedigree of that strain is shown on the tabs of the exposed cards to the left in order of their occurrence in the file, tracing the line back to its source (Fig. 1, "90139–01," "80125–02," "U.S. 215"). All of the progenies of a given source are represented by the cards immediately preceding the source card. For quick reference a card or cards giving a list of all the seed numbers with their corresponding sources is made up in numerical order by seed number each year, using the proper position for that year's progeny, and placed in the front of the file (Fig. 1, "1939"). If it is desired to locate a strain, look at the index card for the year the seed was produced, find the source, follow down the row of tabs for that year until the group filed in front of the proper source card is reached, look through these few cards, and open the file exposing the proper one.

The cards fit a two-drawer metal voucher file, inside measure 5 9/32 inches by 12 inches by 16 inches. However, they may be placed in a cardboard box and kept in other files. When it is desired to have copies of portions of pedigrees, the necessary information may be readily typed from the cards.

It is believed that this method of recording pedigrees will allow each plant breeder to have readily available the complete pedigree of all his selections. This will avoid the possibility of duplicating unfortunate attempts of improvement, especially with related strains, and in general greatly facilitate the breeding program.—FRANK F. LYNES and C. E. CORMANY, *Beet Seed Breeding Department, Holly Sugar Corp., Sheridan, Wyo.*

A GREENHOUSE METHOD OF MAINTAINING SOIL MOISTURE BELOW FIELD CAPACITY[1]

INVESTIGATORS engaged in plant research often have been confronted with the problem of accurate control of soil moisture content in plant containers. It is necessary, in most instances, to make modifications of a common type of irrigation to adapt it to the experiment at hand. The ideal irrigating system is one that will distribute the water evenly throughout the soil mass in a short time.

A system of irrigating soils in containers has been devised whereby the water is distributed fairly uniformly throughout the soil mass at levels below the field capacity. The equipment used is illustrated in Fig. 1. It consists of a glazed clay pot 7 inches in diameter and 9

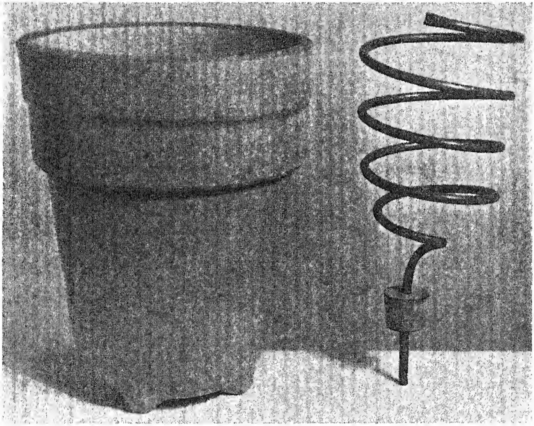

FIG. 1.—Equipment consisting of a 7-inch glazed pot and a copper coil used to insure uniform distribution of water throughout the soil mass.

inches tall, with a hole for a No. 7 rubber stopper in the bottom. The irrigating coil (Fig. 1) was made from ¼-inch copper tubing 4½ feet long. Before coiling, two rows of holes approximately 1/64 inch in diameter are drilled or punched at 1-inch intervals approximately diametrically opposite for the length of the tube, except that portion which passes through the stopper. The upper end of the tube is closed.

[1]Joint contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, and the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans. Contribution No. 318, Department of Agronomy.

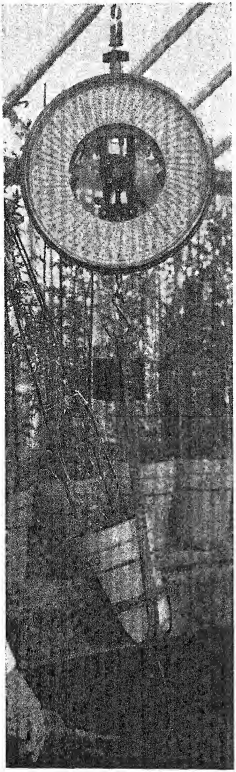

FIG. 2.—Applying water from a water hydrant.

The tube then is coiled on a grooved wooden form made for that purpose.

Used phonograph needles, instead of a drill bit, were found to be satisfactory for use in a drill press to make the holes in the copper tube. A press equipped with an adjustable depth gauge will insure uniform diameter of the holes.

The irrigating system is used by applying the water from a water hydrant, as shown in Fig. 2. In this case the water hydrant had approximately a 50-pound pressure. An air pressure system also has been used successfully.

After using this equipment with alfalfa experiments for 3 years it has been found to be a satisfactory method of controlling soil moisture. It is now being used by other investigators at this station with wheat and sorghum plants.

No particles of soil are more than 1½ inches from the source of water and by using pressure the water is applied quickly and distributed evenly. Small holes are used in the tubing in order to give the spray effect from the pressure applied.

Tests were conducted to determine the rapidity with which a uniform distribution of the moisture might be expected at different percentage soil moisture levels. Table 1 shows the results obtained in a test where the moisture was held near 14.5 and 18.5% of the dry weight of the soil, respectively.

The average moisture content of the soil in all pots did not deviate more than 1.2% from the desired average.

Following an experiment in which alfalfa plants were grown to maturity, the pots were checked for soil moisture with the following results: Under high soil moisture conditions where the soil moisture was being held at 22% the average was 21.3; in the low moisture pots where the soil was to be held at 10%, the average was found to be 12.2%. The soil used in this experiment was made up by mixing 2½

TABLE 1.—*Percentage soil moisture at different soil levels 2 hours after watering.*

Percentage soil moisture	Pot No.	Percentage water in soil at different depths in pot			
		1st inch	4th inch	7th inch	Pot average
14.5	1	13.15	14.49	14.63	14.09
	2	14.77	15.07	14.47	14.77
	3	14.28	12.37	14.06	13.57
18.5	4	17.89	18.05	16.88	17.60
	5	18.85	——	19.51	19.18
	6	19.27	19.23	18.82	19.11

parts of silt loam, 1 part of medium sand, and ½ part compost, and had a moisture holding capacity of 25%. A root examination showed there was an even distribution of roots throughout the soil with no concentration of roots around the coil.—C. O. GRANDFIELD, *U. S. Department of Agriculture.*

THE TEACHING OF QUANTITATIVE PLANT BIOLOGY

AS was indicated in a previous note in this JOURNAL, (Vol. 33, pages 262–263), the publication of my address on "The Education of an Agrobiologist" has evoked communications from a number of agronomists and plant physiologists. Some of these correspondents disclose that they have been giving agrobiology a definite place in their teaching and have assigned thesis work in it. One head professor of soils in a prominent western university makes the interesting suggestion that the term "agronomist," with its connotation of hand-to-mouth farm management restricted on all sides by dollar signs, is a misnomer when applied to research workers who are engaged in scientifically evaluating the compositions and the yields of plants in terms of external factors; such men, he thinks, would be more correctly classified if called agrobiologists.

However, there have been a number of letters from professors and station workers who definitely have not acquired an agrobiologic viewpoint. I have been much interested in studying this kind of letter in an effort to identify the mental complexes that seem to be impeding the teaching of plant culture as the real science that it is. One typical case was discussed in the note just referred to; another case is here presented.

In this second case a copy of my address was sent to the president of a state college along with a letter advising him that, on the basis of present information and of known conditions there existing, his college was not included in a list of institutions where adequate instruction in the fundamentals of quantitative plant biology might be had.

This communication started the following sequence of actions: The president called on the dean of the school of agriculture for a report on alleged conditions that could afford a basis for a reflection on the quality of instruction given by the institution. The dean in his

turn called on the head professor of agronomy for a written statement which would refute the allegation that the college was no fit place for students who wanted instruction in the fundamentals of quantitative plant biology. Thereupon the professor produced a letter to the dean, and the dean kindly forwarded the letter to me. This letter is here reproduced in its entirety:

"On page 5 Dr. Willcox states what he calls the three basic principles of agrobiology. The first, in effect, is that the same conditions bring about the same results. This is generally accepted. The second is the absolute differentiation of plant species by their quantities of life. If he is using the term species as botanists use the term, it means little. In cultivated plants there is too much of a difference between varieties to accept this as a general truth. The third principle, as to increments of fertilizing elements, is generally accepted.

"The formula for mass action, pages 6 and 7, may be a reasonable hypothesis, but what of it? If each of the growth factors is represented at a certain percentage of its optimum condition one could compute what the result would be in terms of the greatest possible growth, but of what value is such a formula when we do not know what the optimum conditions are for the factors involved? If we did know that, of what value would it be when we must grow plants under conditions over which we do not have control?"

From the circumstances of its origin the foregoing letter has to be regarded as an official declaration of the position taken by this agronomy professor and his college on the question of teaching quantitative plant biology, and as an answer to an allegation that the college was no fit place for students wanting such instruction. We will therefore subject it to a critical examination in an effort to visualize how much and what kind of instruction in quantitative plant biology the agronomy students at that college are likely to get.

In the first paragraph of the professor's letter we find that he accepts the principle that plant yields are quantitatively reproducible in a constant environment; he rejects the principle that plant species are characterized by their possession of definite quantities of plant life; and accepts the principle that growth factors increase the yields of plants by diminishing increments.

At first sight this looks as though agrobiology wins two points out of three. In reality, in losing one of its three fundamental principles, agrobiology suffers a complete and irretrievable defeat. To make a simile, an agrobiologist may be compared with an artilleryman who has been ordered to fire on the advancing enemy. To execute that order the artilleryman must coordinate three essential elements, a gun, powder, and a projectile. Deprive him of any one of these and he can do nothing. Deprive agrobiology of one of its basic principles and it will not mean even a little. "*Quantity of plant life*" is of the very essence of quantitative plant biology. It is, or the ordinary man will think it is, chief among all the matters with which workers in experiment stations and teachers in agricultural colleges should concern themselves. And the ordinary man might easily be led to believe that, where these workers and these teachers have little or no notion of quantity of plant life as something to which definite and constant

magnitude can be assigned, neither their work nor their teaching will amount to much.

However, our agronomy professor introduces what looks like a saving clause, but which may be interpreted as an indication that he did not give the matter all the thought and study that the occasion demanded. The validity of the second principle is hung on an "if"; it will mean little, he says, *if* the term species is used as botanists use it. *If* he had ever read even one book on agrobiology he would know how agrobiologists use it. In the agrobiologic sense a species is a unique form of plant life; a pure-bred, homozygous genotype; a stabilized composite agrotype that can be treated as a constant entity; in other words a distinct and unmistakeable variety.

To a botanist sugar cane is *Saccharum officinarum*, of which cane breeders are producing literally thousands of new varieties every year. But on a sugar cane plantation you will most likely find only one, and that one is apt to be *POJ 2878*, which is distinguished by the possession of a larger quantity of life than has yet been found in any other. This *POJ 2878* is propagated as a clon, and every botanist knows that a clon reproduces itself (except for rare mutants) with absolute fidelity down to the last minute detail, including its characteristic quantity of life.

Again, to the botanist, the sugar beet is a subspecies of *Beta vulgaris*, of which there are innumerable variants. To the field man of a beet sugar factory it may mean only *Kleinwanzleben E*, the one variety that has the largest quantity of life of its kind. Now, this *Kleinwanzleben E* is not a homozygous genotype; it is a mixture of biotypes which the beet breeders have not been able to separate. But this aggregation of biotypes behaves as a unit; the quantities of life inherent in the biotypes, each constant in itself, sum up to a varietal constant that can be and is taken as a basis for calculation. That is to say, this variety of sugar beet is a stabilized agrotype. To argue against the second principle that there is "too much difference between varieties" is wholly pointless.

Approaching the second paragraph of the professor's letter to his dean, we find that the agrobiologic mass action law is given the status of a hypothesis that may be reasonable but is of no practical interest even if true. It may be premised, he says, that if we could identify a certain percentage of the "optimum condition" of a growth factor we might compute a maximum end-result. But the sad fact, as he sees it, is (a) that we do not know anything about what the optimum conditions are; and (b) even if we did know what the optimum conditions are we would be no better off, because we must grow plants under conditions over which we have no control.

Here the professor states two propositions, (a) and (b), which complete the illumination by which we may judge the extent and quality of the instruction in quantitative plant biology at his college. Judging from what has been officially set before us, we conclude that he is not giving adequate instruction in those quantitative phases of plant life which should be included in the training of plant culturists whose chief interest in plants is to get from them their maximum yields. There is here no conception, or a conception that is wholly

inadequate, of the three fundamentals out of which a quantitative science of plant yields must come. Naturally, in such an atmosphere details will not be recognized for what they are, even if seen at all. There will be no talk of the known Baule units of growth factors, or of their known correlations with known units of quantity of plant life. Perultra and subultra agrotypes, perultimate and subultimate yields, perfertile soil, the inverse yield nitrogen law might as well be so many Chinese hieroglyphics that evoke no definite ideas in the minds of either teacher or pupil.

Specifically as to proposition (a), we recommend to this head professor of agronomy, and to all others who find it necessary to confess that they do not know "what the optimum conditions are for the factors involved", that they inform themselves as to what the agrobiologists have done about that matter. And specifically as to proposition (b), we recommend that agronomy professors beware of deepening the disgrace of defeatism that already lies heavily on many of them (cf. the previous note). Uncontrollable conditions, forsooth! Will somebody please name a field condition that, if not controllable, may at least be evaded or reduced to a known minimum dimension. Why are experiment stations and agronomy professors supported by the public if not to point a way to control conditions in the fields, or if uncontrollable at least to evade or reduce them to known minimum dimensions?

And of two agronomists, which is the more likely to distinguish a controllable from an uncontrollable condition and the more likely to succeed in reducing the uncontrollable ones to minimum dimensions—the one who knows the measures of growth factors and quantities of plant life in definite units, or the one for whom a Baule unit has no significance and to whom the graph of the law of diminishing increments is still an unintelligible scribble?—O. W. WILLCOX, *107 Union Street, Ridgewood, N. J.*

BOOK REVIEWS

AMERICAN FARMERS IN THE WORLD CRISIS

By Carl T. Schmidt. New York: Oxford University Press. XI+345 pages, illus. 1941. $3.

THE value of this book for agronomists lies in its very readable presentation of the economic and political background of the efforts of government to cope with farm problems in the United States, particularly the so-called "action" programs in which many agronomists are directly concerned. Knowledge of the economic significance, both present and future, of these programs is as essential to wise planning and administration of the programs as a sound scientific foundation for the recommended practices.

The author served as Senior Agricultural Economist of the AAA for two years, was a Research Fellow in the Social Science Research Council and a lecturer in economics at Columbia University, and is

now on active duty with the United States Army as a captain of infantry.

The text is supplemented with notes on source material, a selected bibliography of general works on current problems of American agriculture, and a good index. In addition to charts illustrating various points, a number of newspaper cartoons reminiscent of the political aspects of efforts at agricultural adjustments during the past few years add much to the interest of the book. (J. D. L.)

MODERN FRUIT PRODUCTION

By Joseph Harvey Gourley and Freeman Smith Howlett. New York: The Macmillan Company. VII+579 pages, illus. 1941. $4.50.

THIS book represents a complete rewriting and expansion of the "Text-book of Pomology" written by the senior author some years ago, and deals with the deciduous fruits of the north temperate zone.

It comprises seventeen chapters, the enumeration of which give a good perspective of its scope and general nature, as follows: The fruit industry, the plant and its parts, factors affecting flower formation, site and soil for the fruit plantation, laying out and planting the orchard, cultural practices, fertilizers and manures for the orchard, water relations of fruit plants, pruning of fruit plants, fruit setting, fruit thinning and alternate bearing, the handling and storage of fruit, winter injury, nutrient deficiencies and physiological disorders, propagation and stocks, the origin and improvement of fruits, and orchard, vineyard, and small fruit costs.

The economics of fruit production are but briefly discussed, and insect and disease control are not included. The chief emphasis is upon the plant itself and its relation to its environment. It may be thought of as a presentation and interpretation of physiology, morphology, soils, chemistry, and other fundamental sciences in terms of fruit plants and their products.

The authors view pomology as having developed into a science in its own right, yet they emphasize that the horticulturist must remember that he represents a vast industry and that scientific efforts and leadership must be based upon practical considerations. From this point of view, they place in the book only such material as forms a basis for modern fruit production.

Quite naturally, because of the size of the apple industry, the apple receives chief consideration, yet the other tree fruits as well as vineyard plants and small fruits are also adequately treated. The chapters on structure, morphology, and fruit setting are especially well done. Likewise, the chapters on stocks and propagation and plant nutrient deficiencies and soils are particularly good. In the emphasis placed upon these subjects the book shows its modern trend.

The authors have done well in their choice of material and in the selection of ample literature citations. In presentation it lies mid-way between the more popular practice text books on similar topics and the more technical books on fundamental sciences. (H. B. T.)

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AGRONOMIC AFFAIRS

NEWS ITEMS

DOCTOR C. H. GOULDEN, Senior Agricultural Scientist of the Dominion Rust Research Laboratory, Winnipeg, Manitoba, Canada, gave the tenth series of Frank Azor Spragg Memorial Lectures, February 25 to 28, 1941, at Michigan State College, East Lansing, Mich. The memorial lecture proper dealt with "The Fundamentals of Experimentation". The four daily lectures had as their general theme, "The Design and Analysis of Experiments".

—A—

DOCTOR H. L. WALSTER, Dean of Agriculture and Director of the Experiment Station at the North Dakota Agricultural College, Fargo, N. D., is one of a party of 10 college and newspaper men recently invited to participate in a good-will tour of several South American countries. The tour is arranged and sponsored by the Carnegie Endowment for International Peace. The party sailed from New York February 28 on the S. S. Santa Lucia. Countries which will be visited are Chile, Argentina, Uruguay, and Brazil. The party expects to be away about two months.

—A—

PROFESSOR C. A. MICHELS, Assistant Agronomist of the Idaho Agricultural Experiment Station in charge of plant breeding work, died suddenly on February 21. Professor Michels had been connected with the Idaho Experiment Station since 1928.

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THE ANNUAL MEETING of the Canadian Seed Growers' Association will be held this year at Macdonald College and the Oka Agricultural Institute, P.Q., on June 18 and 19.

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VOL. 33 MAY, 1941 No. 5

THE WAR AND OUR CHANGING AGRICULTURE[1]

ERIC ENGLUND[2]

THIS topic recognizes that agriculture is constantly changing, and suggests that the present war should be considered, not only in relation to a stationary picture of American agriculture taken as of December 1940, but also in connection with the changes that characterized our agriculture in the past and that were influencing its future when the war began. In the wording your program committee gave a helpful suggestion on how the subject should be treated.

Agronomists, accustomed as they are to dealing with natural forces, probably are inclined to take a long view of change. Economists, however, usually deal with issues of the moment and may lose sight of forces that are reflected in long trends often temporarily obscured by current events. Perhaps we would improve our perspective and judge the present more clearly if we should more often consider present problems, including the economic impacts of this war, in relation to historical forces and long-time change.

The war and related disturbances among nations necessitated our defense program, and both are closely related so far as now concerns their economic influence upon agriculture. The main outline of this influence may be summarized very briefly.

EFFECTS DEPEND ON SCOPE, LENGTH, AND OUTCOME OF WAR

The defense program has stimulated and will further stimulate industrial activity, prices, employment, consumer income, and domestic demand for farm products. The extent and scope of that program and of the economic stimulus from it depend on the scope and duration of the war, the sort of peace that will follow, and the situation that confronts our nation and this hemisphere in the post-war world.

Foreign markets have virtually disappeared, and prospects for their revival are decidedly unfavorable. In general, the commodities mainly on a domestic market basis will be influenced more by the

[1]Presented as part of a symposium on "War and Agricultural Adjustment with Special Reference to Grassland Agriculture" before the Crops Section of the American Society of Agronomy and the Soil Science Society of America, Chicago, Ill., December 6, 1940.

[2]Assistant Chief, Bureau of Agricultural Economics, U. S. Dept. of Agriculture, Washington, D. C.

increased domestic demand than will the great export products. Being on an export basis and therefore in oversupply for domestic requirements, these products will benefit less by the improved domestic demand. This has obvious regional implications in our agricultural economy and points to more intensive but not unfamiliar problems of adjustment. The seriousness of these implications and problems also depends on the scope, duration, and outcome of the war and on the economic world order emerging after the war ends. "The shape of things to come" after the war, will certainly depend very largely on the political and economic philosophy of the nations, or combination of nations, that will then dominate Europe, Asia, and other parts of the world.

It is possible that trade may be severely channelized and regimented under bilateral agreements and other arrangements by which imports would be handled through centrally dominated agencies which in effect would be arms of the governments. If this should be the dominant system, trade would not necessarily be conducted on the basis of the customary standards of cost and competition, profit and loss, that have characterized international trade through private channels. In that event, we would be dealing, not with independent firms and individuals abroad, but with governmental agencies representing colossal concentration and regimentation of trade beyond anything we have yet experienced.

On the other hand, even if a greater degree of liberalism should prevail in the post-war world, it is unlikely that such control devices as purchasing commissions, exchange quotas, preferential treatments, etc., would be demobilized soon upon the conclusion of peace. This would not be inconsistent with the ultimate return of liberalism in trade, even though nations accepted regimentation of international trade as a current necessity.

A long war would increase the possibility of price inflation. We have not yet experienced any appreciable tendency in that direction, for even now our productive capacity is far from utilized to the fullest; we still have unused plant capacity in many industries, and substantial unemployment. We probably should not expect any significant tendency toward price inflation until the general demand for goods begins to press against the existing capacity to produce. Even then we need not expect a huge inflation as a matter of course, for we have more control over inflationary forces now than in the last war. Prevention of inflation would make most of the economic effects of the war less severe, and farmers, along with others, would be in a far better position to face the economic aftermath.

We may be certain, whatever the outcome, that the post-war world will be very different and that freedom of trade in the old sense is not likely to return in our time. While striving to prepare ourselves for whatever may come, we should realize that trade is not all we have at stake and that agriculture along with the rest may be vitally affected by political, social, and ideological changes.

Agriculture is probably our chief stronghold of that spirit of individual responsibility and personal freedom on which democracy has been built. It represents a way of life, a standard of values, the

essential elements of which we are determined to preserve in this country. World forces are challenging that way of life as never before in our history; and this must not be forgotten even when our attention is centered on economic change, for economic change does not stand apart, except by abstraction, from other and more important human values.

Let us return, however, to a brief review of major changes in agriculture over a period of years, and note the possible bearing of the war and of our defense program on them.

DIMINISHING EXPORTS, A LONG TREND

The very drastic curtailment in farm exports since this war began represents perhaps the most advanced and accelerated stage of a trend well under way for many years. Seven years ago, in a study of world trade barriers in relation to American agriculture,[3] the Bureau of Agricultural Economics pointed out that many trade restrictions were even then in effect. These included high tariffs both here and abroad, exchange restrictions, milling quotas, and numerous other devices applied in foreign countries to limit trade.

The purposes were varied: (1) To protect farmers by resisting the drop in prices, especially in the world-wide depression that began in 1929–30; (2) to influence balances of international payments for the purpose of protecting gold supplies and the exchange value of national currencies; (3) to promote solidarity of the British Empire through Empire trade preferences; (4) to make nations normally dependent upon imports more self-sufficient as to food supply and thereby to strengthen their position in case of war; and (5) to conserve the available foreign exchange for the purchase abroad of certain strategic material essential to armament programs.

These measures had already imposed severe restrictions on our exports seven years ago, and the multiplicity of devices and their restrictive effect continued to increase until the outbreak of this war. Our trade-agreement program represented perhaps the only extensive effort in the opposite direction, but its effect on international trade was probably small in relation to the total influence of mounting trade restrictions which culminated in the embargoes and blockades that are now weapons of total warfare.

The effect of these restrictions on foreign competition and demand for our farm products abroad was to limit directly our exports and to stimulate production of agricultural products in many foreign countries and thus curtail the requirements for our grain, lard, cotton, and many other commodities of which we normally exported large quantities.

Meanwhile, and largely as a result of the World War of 1914–18, our exports were further restricted by our sudden transition from a debtor to a creditor nation. Our debts prior to the last war consisted mainly in foreign investments in our industries, transportation

[3] "World Trade Barriers in Relation to American Agriculture," prepared in response to Senate Resolution No. 280, Seventy-second Congress, and published as Senate Document No. 70, of the 73rd Congress, 1st Session.

system, and other parts of our then rapidly expanding economy. Interest amounted to about $200,000,000 annually, which, together with other payments to foreign countries, was made in large part with farm exports. The shock of our sudden reversal to a creditor status was cushioned for a few years by large post-war loans by which we in effect lent money to foreigners to buy our products.

Meanwhile we persisted in our tariff policies limiting our imports from abroad by which alone, in the long run, foreigners could pay for our exports and service their debts to us. This combination of world-wide trade restrictions and our shift to a creditor status without a corresponding change in our trade policy, exerted sharp pressure against our exportable surplus of farm products, especially in the latter part of the 20's when our loans to foreigners had substantially ended.

Associated with, but not wholly dependent on, the mounting trade restrictions is the decline in our agricultural exports. In terms of physical volume exported, our dependence on the foreign market has diminished, especially in the past decade. This decline suggests, but does not measure, the pressure of contracting markets abroad, for other factors have influenced export trends. It is in prices and income that the pressure of trade restrictions is really felt, because of the familiar fact that prices received for the exportable surplus largely determine the prices of the domestically consumed part of the total supply.

As shown in Table 1, exports of pork, lard, grain, and cotton were greatly reduced even before this war. In the past decade and longer, fruit, especially apples and citrus, and to some extent tobacco, represent departures from the general trend of total farm exports, tobacco having held its own up to the present war and fruits having increased rapidly. Since this war began, however, exports of these products also have been sharply reduced.

TABLE 1.—*Volume of agricultural products exported from the United States.**

Commodity	Average				1938–39	1939–40	July–September†	
	1909–10–1913–14	1915–16–1919–20	1924–25–1928–29	1934–35–1936–37			1939	1940
Total agricultural exports	100	123	119	57	63	72	58	28
Cured pork	100	343	99	17	21	17	23	4
Lard	100	109	155	30	51	54	62	41
Grains and grain products	100	225	178	20	125	64	78	57
Cotton, unmanufactured	100	67	102	68	44	78	52	15
Tobacco, unmanufactured	100	123	130	104	121	87	97	38
Fruits	100	101	265	222	316	170	174	38

*Years ended June 30.
†Average of monthly index numbers.

It appears that those changes in agriculture which are represented by our exports of farm products, with the possible exception of

tobacco and fruit, will be accelerated by the effect of the war. In the future, fully as much as in the past, we shall have with us such problems as too much cotton for our foreign market outlets, too large an exportable surplus of wheat and of lard. The resulting repercussions are familiar, both in their national and regional patterns.

STABILITY OF TOTAL FARM PRODUCTION

Certain trends, indicative of agricultural change, also are shown by the volume of agricultural production, especially when export products are separated from the rest. Total production has shown a remarkable stability in the past two decades. After increasing gradually from 1919 to 1925, reaching in the latter year 97% of the 1924–29 average, it has since fluctuated moderately around that average, with a high of 109% in 1937, and a low of 92% in 1935 due mainly to the drought. Products on a foreign market basis include chiefly cotton, wheat, hogs, tobacco, apples, and citrus fruit. Chief among those on a domestic market basis are dairy products, poultry, beef cattle, sheep and wool, and truck crops.

Table 2 shows total agricultural production in the past 22 years and shows separately the production of the specified "export commodities" and all other commodities in the total. Production of the latter, including chiefly the farm products that are on a domestic market basis, increased substantially in recent years above the 1924–29 average, while the production of the "export commodities" averaged below that level for more than a decade. This divergence of trends, though not wide, indicates a steady change of emphasis, partly in response to adjustment programs, toward "domestic-market" products.

Total farm production in the past four years (1937–40) averaged about 7% above the 1924–29 level and in the preceding four years (1933–36) only about 5% below that level despite exceptionally severe drought years. The causes of this stability lie not only in the dependence of farming on natural forces, but in the nature of agriculture itself which precludes that vast contraction of production characteristic of industry in depression years.

Agriculture consists of numerous small competing units of operations in which labor, management and ownership are so closely interrelated and the ratio of overhead costs to direct costs so large that *total* production is not significantly curtailed in response to lower prices. But industry is very different; its productivity in 1933 was curtailed by 40% below the 1924–29 level, did not regain that level until 1936, and fell 8% below it in 1938. It is estimated that war orders and the defense program may raise the level to 25% above in 1940.

Agriculture has changed relatively little in the basic characteristics that account for the persistence of its total productivity, while industrial change seems to have congealed into greater instability and sharper curtailment of output in depression years. This difference is of great significance to agriculture and to the rest of our economy. In depression years, farm prices and income, under the weight of

TABLE 2.—*Index numbers of the volume of agricultural production for sale and for consumption in the farm home, 1919–40.**

(1924–29 = 100)

Year	All commodities	Specified "export" commodities†	All commodities less specified "export" commodities
1919	87	92	83
1920	91	94	88
1921	83	76	87
1922	92	87	95
1923	95	92	96
1924	97	99	95
1925	97	96	98
1926	102	106	99
1927	99	94	103
1928	104	105	104
1929	101	100	102
1930	101	98	103
1931	107	108	106
1932	100	92	105
1933	97	92	100
1934	94	79	103
1935	92	74	104
1936	95	82	103
1937	109	106	111
1938	104	94	111
1939‡	107	97	114
1940§	108	104	111

*1924–29 = 100.

†Specified "export" commodities include wheat, cotton lint, tobacco, apples, citrus fruits, and hogs. Other agricultural products are exported to a lesser extent but the commodities listed which represent a major share of our agricultural exports reflect adequately the trend in the production of "export" commodities.

‡Preliminary.

§Tentative estimate.

persistent abundance, fall to very low levels. Because of the rigidity of other prices held up by curtailed production, the exchange value of farm products also falls. Yet agriculture continues to supply the rest of society with an undiminished abundance of necessaries of life, and gets in return the meager reward afforded by curtailed production and rigid prices in other fields. Data suggestive of certain intergroup relationships in production, prices, and income are shown in Table 3.

In this manner agriculture in reality gives to the rest of society in times of depression a huge subsidy, an unrewarded contribution, in the form of "use values" which if measured in dollars over the past 10 years would be many times greater than the Government's "farm subsidies". If agriculture had failed to function as the great shock absorber in our economy, that is if it had succeeded in curtailing production to the extent that it was curtailed by industry and labor, the shock to our whole economic and social structure might have been very disruptive.

The persistent abundance of agriculture and its ready capacity to produce even more if needed are a source of basic strength in our

TABLE 3.—*Production, prices, and income in agriculture and industry, 1924-40.**
(1924-29 = 100)

Year	Production		Prices			Income			
	Volume of agricultural production	Industrial production of manufactures†	Received by farmers	Paid by farmers	Industrial prices‡	Cash farm income§	Income from manufacturing**	Industrial wage rates††	Income of industrial workers
1924	97	85	98	99	99	94	88	96	94
1925	97	94	106	102	104	102	96	98	98
1926	102	100	99	101	103	98	103	100	102
1927	99	100	95	99	98	99	98	101	100
1928	104	105	102	101	99	103	102	102	100
1929	101	116	100	99	97	104	113	104	107
1930	101	96	86	94	91	83	83	100	88
1931	107	78	60	81	79	58	57	91	67
1932	100	60	45	69	72	44	33	79	46
1933	97	72	48	71	73	49	45	75	48
1934	94	78	62	80	81	58	58	80	61
1935	92	92	74	81	85	65	69	84	69
1936	95	109	78	81	84	76	83	88	80
1937	109	119	83	84	90	81	94	95	94
1938	104	92	65	79	85	71	69	91	73
1939	107	114	64	79	83	72	86	94	83
1940‖	108	127	67	79	84	77	95	98	93

*1924-29 = 100.
†Federal Reserve Board index converted from 1935-39 base.
‡Bureau of Labor Statistics index of wholesale prices of finished products converted from 1926 base.
§Excluding Government payments.
**1920-39, Bureau of Foreign and Domestic Commerce estimates of income produced converted to 1924-29 base.
††Average weekly earnings in New York State factories reported in the Industrial Bulletin of New York State converted to 1924-29 base.
‖Preliminary.

defense effort, despite current problems of price and markets. This strength is probably taken for granted for it has persisted so long. After the war and the defense effort, we may face another depression. Then no doubt agriculture will again be the shock absorber and the great source of necessaries for which the rest of our economy will give inadequate reward in exchange, unless by then we shall have succeeded in devising technic and motivation for a persistence of industrial output comparable to that of agriculture, the key to "balanced abundance".

CONTINUING TECHNOLOGICAL CHANGE

Technological improvements represent another phase of our changing agriculture, and this change has been rapid, as shown in a recent

publication by the Bureau of Agricultural Economics.[4] As this field of agricultural change is familiar to this Society, it will suffice to mention only a few examples, such as the shift from horse power to motor power, crop improvements, increased livestock efficiency through animal breeding, and rural electrification.

To the extent that the war and the defense program will result in better farm returns and increased demand for labor, it is probable that technological improvements will be accelerated.

FARM POPULATION TREND CONTINUED

Population trends represent another major change in agriculture. Total population in the United States is increasing, but at a diminishing rate. Farm population, on the other hand, has remained practically stationary over the past 30 years, having increased only from 32,000,000 in 1910 to 32,245,000 in 1940. The proportion which farm population is of total population declined from 34% in 1910–14 to slightly under 25% in 1940. The relatively minor variations in farm population in the past 30 years are attributable mainly to changes in economic opportunity outside of farm communities.

The war and the defense program are likely to cause an increase in the net movement of population from farms because of increased demand for labor in the defense industries and in other industrial activity and the manpower requirements of our defense forces. These changes affecting agriculture are in the same direction as the changes experienced in other periods of rising business activity and increased labor requirements, and will not alter the fundamental population trends of the past several decades. If after this war is over, we should succeed in achieving and maintaining full employment and that rising level of production which technological improvements and our resources would make possible, then we may well expect farm population to decline both in numbers and in percentage of total population, especially as the latter approaches a stationary level. With such expansion in nonagricultural production, total farm income would represent a diminishing percentage of the national income, but probably not a diminishing percentage per family or per capita.

SOME LESS TANGIBLE CHANGES

Other changes in agriculture, more general than those that are measurable in terms of exports, production, population, etc., may also be influenced by the war and related forces.

In the past few decades and longer the results of agricultural research have grown in amount and in application. Educational work through numerous channels—colleges, extension, vocational agriculture, program participation, press, and radio—has produced among farmers a greater alertness toward new ideas, and a more receptive attitude toward research and its application to practical

[4]"Technology on the Farm," a special report by the Interbureau Committee and the Bureau of Agricultural Economics of the U. S. Dept. of Agriculture, August 1940.

problems, and even patient willingness to experiment with innovations in public plans and programs. These programs are adaptable tools for meeting new problems that require concerted action. In this respect we are far better off than in the last war.

New and practical discoveries are applied rapidly, as illustrated by the spread of hybrid corn. Programs which a few years ago might have been considered too revolutionary are now participated in by the great majority of farmers. Participation is not confined to programs which bring direct financial reward, for an increasing number are active in land use planning, extension programs, and other non-paid activities. Research is not looked upon as "book learning", but is supported and used even by farmers with little formal education, but who believe in research and fuse it with their experience. All this means flexibility in agriculture, greater adaptability of farming and of rural people to change.

The attitude of the non-farming public toward agriculture also has changed, due to economic and social education and to the political education that has resulted from organized representation of the interests of farmers in Congress and in the state legislatures. Agriculture now sits at the council table on a plane of equality with the rest.

It may not be too optimistic to believe that, despite the conflict of interest among economic groups, there is emerging a wider realization of an over-all common interest and stronger conviction that if this common interest is violated by excessive demands of this or that group serious consequences will follow not only to society as a whole but also to the particular violator of the common interest. This may account in large part for the acquiescence and even the wholehearted support which urban interests through elected representatives have given to agricultural programs in recent years. For example, no longer is it widely insisted, as it was only a dozen years ago, that national support for extension work, research, good roads, etc., gives too much benefit to agricultural areas at the expense of the populous and more wealthy centers.

This change of public attitude toward agriculture partly accounts for the much greater participation by government—some choose to call it interference—in agricultural matters. The public interest is more and more concerned with the less fortunate, and programs are aimed specifically at raising them to a higher level of economic and social advantages. This change is certain to be accelerated by war and by the aftermath which it may bring.

EXISTING MAJOR CHANGES ACCELERATED

Great wars have always caused much change in our agriculture. For example, the Napoleonic wars greatly inflated our price level and were perhaps decisive in bringing about the Louisiana Purchase which added an agricultural empire to our national domain. The Civil War produced the Land Grant College Act and the Homestead Act, with the resulting acceleration of westward expansion. The World War, as already noted, changed our status from a debtor to a creditor

nation with profound effects on our agriculture; and produced an inflation of prices and of farm values and debts from which we have not yet fully recovered. It set the stage for political change and for the growth of economic restrictions in the international field which limited trade and may have contributed much to bringing on the present war.

This war and our defense program are intensifying and accelerating, with only minor exceptions, the already existing pattern of change in agriculture—our export markets further limited, emphasis shifting toward production for the domestic market, technological change further accelerated, farm population further diminished, and governmental action and public programs playing a larger role. The direction of change is the same and to this extent we are on fairly familiar ground and may be assured that much work has already been done to prepare for changes to come.

THE WAR NO SOLUTION OF MAJOR FARM PROBLEMS

This, however, does not mean that the impact of the war will bring no serious problems of adjustment in agriculture. On the contrary, those problems which have occupied our attention for years are likely to be intensified, and new ones may appear especially in the aftermath of war.

Low farm income and unfavorable ratio of prices received to prices paid by farmers represent the chief farm problem, and this is not likely to be solved by the war and the defense program. The latter will offset, at least in part, the repressive effect of the war on our farm exports, but the offset will not be distributed uniformly among the farming regions or equally between the export and the domestic-market commodities. The underlying causes of this problem will not be solved, but may be obscured for a time by the war and the defense program and may even be aggravated in the aftermath of war especially if it should end in a world order that would perpetuate the limitations on trade.

Perhaps the best that can be expected is a temporary easing of the pressure of low agricultural income, unless we should achieve that economic organization and motivation that would greatly increase the production of goods and services outside of agriculture and distribute widely the buying power based on the increased productivity.

Agricultural indebtedness would be reduced as a result of the expected increase in farm income only if farmers when times improve should be an exception to the rule and pay off old debts. The more usual practice of most people is to incur new and larger debts in the expectation of bright years ahead.

Even if farm income should increase substantially there are reasons for believing that a serious expansion of farm debt is less likely now than in the last war: Prices and income are not expected to rise as much now as then, and we have a vivid recollection of the disasters that resulted from inflated indebtedness 20 years ago. Owners and prospective buyers of land now have faced 20 years of declining farm real estate values and low prices and income as against 20 years of

increasing prices and income and an indefinite period of increasing land values prior to the last World War. Costs in agriculture may advance as fast and in some cases even faster than prices of some of the major farm products that are on an export basis. Economic information is now more adequate and there is better and more widespread public knowledge of economic forces. Educational and action agencies now have far-reaching contact with farmers and the public and should be in a position to induce greater steadiness and caution and to exercise restraining controls if needed.

Low-income groups in agriculture represent another set of problems now receiving increased public attention. While the war and the defense program may to some extent alleviate the lot of these groups, the underlying causes—physical, economic, social and individual—are not likely to be solved by the war impacts or by the business stimulus of the defense program. But those basic improvements in industry and in agriculture, in marketing and in finance, and the human motivation and change of individual habits which are necessary to a healthy economy probably are attainable only through long-time programs carried forward with a persistent social purpose. This purpose may be strengthened by the dangers that confront us as a nation and by the lessons of tragedy abroad demonstrating that in order to remain free a society must be unified and strong.

As a direct outgrowth of the defense effort, a program for improved nutrition is in the making that may go far to improve the health and efficiency of the people and at the same time broaden the domestic outlet for such products as truck crops, fruit, meats, and dairy and poultry products. This program would contribute to national strength through improved health and efficiency and at the same time widen the domestic outlet for products that would be grown in greater quantity under the expected acceleration of change in farming. This potentiality is suggested by the estimate that an adequate diet for all in the United States would increase consumption of vegetables about 50% and of dairy products 15 to 25%. Consumption of fruits and meats also would be increased.

It would be useless to hope that soil erosion and depletion of soil fertility will be reversed or that the broad problem of land use will be solved by war impacts. The pressure is likely to be in the opposite direction, especially if there should eventually be a market premium upon soil depleting crops and upon that type of cultivation which hastens erosion. This, however, seems less likely than was the case in the last war because of the present unfavorable position of our great export crops. Unless the war and the defense effort should absorb public interest and resources to such an extent in the next few years as to preclude for a time full continuation of the land use and conservation programs already under way, it is probable that these programs will go forward as the basic reasons for them will remain.

Shifts from export crops to other crops and livestock will in the main conform to desirable land use and conservation practices. These shifts, however, will not be simple or without real stress and strain in the various regions and in the competition among regions for domestic market outlets. One set of problems involve adjustments to

systems of farming better suited to the restricted foreign market outlets likely to confront us for many years. The other set of problems has to do with market outlets at home for the products which will be produced in greater quantities as a result of such adjustments in farming. These market outlets in turn depend on a high level of nonfarm production and wide distribution of income in order to afford effective consumer demand through mass purchasing power. On this, more than on any other basis, rests our hope for a higher standard of living for the masses both in rural and urban communities.

FARM ADJUSTMENTS TO MEET WAR IMPACTS[1]

SHERMAN E. JOHNSON[2]

THE general question raised by this topic is, How can farmers who are operating under widely varying conditions throughout the country and producing different combinations of products best adjust their operations to meet war conditions—for their benefit and for the Nation's welfare?

In dealing with this question the first thing discovered is the highly variable effects of the war and the defense program on demand for major commodities. The products normally exported are adversely affected by the war. This means that the dark spots in the demand picture are cotton and tobacco in the South, wheat in the Great Plains and Pacific Northwest, pork and lard in the Midwest, and fruits everywhere that were formerly produced for export.

The bright spots in the demand picture are the domestically consumed dairy and poultry products, meats, wool, and fruits and vegetables. Larger payrolls will mean increased consumption of these products.

Having in mind the demand contrasts among the various products we can analyze better the adjustments that farmers will need to make. It is usually necessary for farmers to look ahead at least 5 years because changes set in motion now will affect production for several years.

The war and the defense program may be totally different in the latter part of a 5-year period. Many more drastic changes than can now be foreseen may be required. However, the outlook for two major commodities probably will be pretty dark regardless of the outcome. These are cotton and wheat. A shift to other alternatives in some of the areas producing these commodities seems highly desirable. The alternatives are already major enterprises in other regions; consequently, interregional competition may be intensified for dairy products, meat animals, wool, and fruits and vegetables.

The basic problem is really one of how many people must find their support in agriculture. If the industrial pick-up would furnish employment for a sufficient number of farm people the *intensity* of production in areas that have lost markets for a part of their production could be slackened. Some of the poorest land could be abandoned and less labor and materials would be used even on the better lands. We could then concentrate on increasing the efficiency of production for the remaining product.

This type of solution would be the same as those of earlier periods. Land in New England was abandoned when the Erie Canal brought cheaper products from the West, but industrial development in

[1]Presented as part of a symposium on "War and Agricultural Adjustment with Special Reference to Grassland Agriculture" before the Crops Section of the American Society of Agronomy and the Soil Science Society of America, Chicago, Ill., December 6, 1940.

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nearby cities created jobs for those displaced from New England farms. However, so long as an adequate amount of nonfarm employment is not available the manpower backed up on farms presses toward *more* rather than *less* intensive uses of land.

The pressure of manpower on the land is the heart of the adjustment problem. Can we suggest any measures for dealing with this situation? If nonfarm employment of part of the present farm population would be the best solution, how can that be brought about? Even temporary employment in defense industries is better than the present situation for farmers in some areas of the South and the Great Plains. The establishment of defense plants in rural areas to permit a combination of rural living and nonfarm work would be even better. To plan for eventual permanent industry in such plants would be best of all.

Direct assistance can be given to farmers who must shift away from products whose markets have shrunk more or less permanently. Shifting means less cotton and tobacco in the South, less wheat in the Great Plains, and less corn in the Corn Belt. Offsetting increases will need to be made in meat and wool, dairy and poultry products, fruits and vegetables, and timber products. In part, these increases in supplies can be used directly by farm families to improve their own living. In part they will make available a better balanced diet for the nonfarm population and will thus contribute to health defense.

Present producers of these products in turn may need assistance to tide over the transition period, for increased supplies may lower their incomes. In this connection it should be remembered that we are building a defense program, and that agriculture should carry its proportionate share of that cost. Greater than proportional costs of adjustment, however, should be borne by society as a whole.

THE PROBLEM BY REGIONS

It is only possible to sketch very briefly the adjustment problems by regions because a detailed picture would have to consider a large number of important smaller areas. As cotton, tobacco, and wheat will be affected most adversely by war conditions, the important producing regions for these crops will be taken up first.

THE SOUTH

Approximately 16 million farm people live in the 13 southern states that stretch from Virginia on the northeast to Texas on the southwest and include a land area of 552 million acres. About one-half the farm population live in this region, but it receives less than one-third of the national farm income.

Adjustments facing cotton farmers provide the outstanding problem in our farm economy. Sixty per cent of southern farm families are dependent on cotton for their primary source of income. Cotton production in 1938 and 1939 averaged about 12 million bales, and the 1940 crop is estimated at 12.8 million bales. As long as war conditions and the defense program are controlling factors, domestic consumption plus exports of cotton probably will approximate only

10 million bales. Present levels of production will, therefore, mean a further accumulation of stocks.

Readjustments in the South would have been necessary under peace conditions. War curtailment of cotton outlets has only accentuated a tough problem. But it has made even more necessary some permanent production adjustments to the shrinking world cotton market that we have experienced for nearly a decade.

When adjustments needed in the agricultural economy of the South are considered, not one but many problems are found. They are widely different. The cotton sharecropper on poor land in the hills of Mississippi who grows his cotton using half-row, one-mule equipment has far different problems than the large-scale cotton farmer on the High Plains of Texas who uses four-row tractor equipment and hired picking labor. Adjustments should therefore be considered in terms of subregions having at least a broad similarity of resources and production opportunities.

If cotton acreage and production in the 1928–32 period are compared with acreage and production in the years 1933–39, it is found that acreage has decreased in all areas (except the irrigated lands of the Southwest) and that production has decreased in the hilly areas west of the Mississippi, the Gulf Coast and Black Prairie Areas of Texas, and also in the western Texas and Oklahoma areas that experienced severe droughts.[3] However, higher production relative to acreage has been maintained in the Coastal Plain, the hilly areas east of the Mississippi, and in the Piedmont. In the river delta areas, production has averaged about 10% above the 1928–32 period; and in the irrigated areas of the Southwest it has averaged nearly 50% above the 1928–32 period.

Do these shifts in acreage and production give any clue to how farmers in these different areas can adjust to the prospective situation? The answer lies in the possibilities of developing alternative uses of land and labor in each of these subregions—uses that will maintain incomes to farm people. Otherwise nonfarm employment must be provided.

In the eastern hill areas it is extremely difficult to outline further adjustments in cotton production that would provide satisfactory returns without large outlays for cotton reduction payments. For example, the only alternatives to cotton that are apparent from recent farm-management studies in some of these areas are the raising of dairy replacements, feeder calves, family subsistence enterprises, and possibly large farm forest units. Further reductions in cotton acreage therefore seem highly improbable unless nonfarm employment for a part of the workers develops rapidly.

The western cotton producing areas, especially the High Plains of Texas, are another subregion in which alternatives to cotton are limited. Production of sorghums, cattle, and in some areas small grain are the best alternatives. Finishing of beef cattle with grain sorghums is practiced to some extent and adoption of a beef cattle system is

[3] "Regional Adjustments to Meet War Impacts," U. S. Dept. of Agriculture, October 1940. (Mimeographed.) See Figs. 6 and 7.

nearby cities created jobs for those displaced from New England farms. However, so long as an adequate amount of nonfarm employment is not available the manpower backed up on farms presses toward *more* rather than *less* intensive uses of land.

The pressure of manpower on the land is the heart of the adjustment problem. Can we suggest any measures for dealing with this situation? If nonfarm employment of part of the present farm population would be the best solution, how can that be brought about? Even temporary employment in defense industries is better than the present situation for farmers in some areas of the South and the Great Plains. The establishment of defense plants in rural areas to permit a combination of rural living and nonfarm work would be even better. To plan for eventual permanent industry in such plants would be best of all.

Direct assistance can be given to farmers who must shift away from products whose markets have shrunk more or less permanently. Shifting means less cotton and tobacco in the South, less wheat in the Great Plains, and less corn in the Corn Belt. Offsetting increases will need to be made in meat and wool, dairy and poultry products, fruits and vegetables, and timber products. In part, these increases in supplies can be used directly by farm families to improve their own living. In part they will make available a better balanced diet for the nonfarm population and will thus contribute to health defense.

Present producers of these products in turn may need assistance to tide over the transition period, for increased supplies may lower their incomes. In this connection it should be remembered that we are building a defense program, and that agriculture should carry its proportionate share of that cost. Greater than proportional costs of adjustment, however, should be borne by society as a whole.

THE PROBLEM BY REGIONS

It is only possible to sketch very briefly the adjustment problems by regions because a detailed picture would have to consider a large number of important smaller areas. As cotton, tobacco, and wheat will be affected most adversely by war conditions, the important producing regions for these crops will be taken up first.

THE SOUTH

Approximately 16 million farm people live in the 13 southern states that stretch from Virginia on the northeast to Texas on the southwest and include a land area of 552 million acres. About one-half the farm population live in this region, but it receives less than one-third of the national farm income.

Adjustments facing cotton farmers provide the outstanding problem in our farm economy. Sixty per cent of southern farm families are dependent on cotton for their primary source of income. Cotton production in 1938 and 1939 averaged about 12 million bales, and the 1940 crop is estimated at 12.8 million bales. As long as war conditions and the defense program are controlling factors, domestic consumption plus exports of cotton probably will approximate only

10 million bales. Present levels of production will, therefore, mean a further accumulation of stocks.

Readjustments in the South would have been necessary under peace conditions. War curtailment of cotton outlets has only accentuated a tough problem. But it has made even more necessary some permanent production adjustments to the shrinking world cotton market that we have experienced for nearly a decade.

When adjustments needed in the agricultural economy of the South are considered, not one but many problems are found. They are widely different. The cotton sharecropper on poor land in the hills of Mississippi who grows his cotton using half-row, one-mule equipment has far different problems than the large-scale cotton farmer on the High Plains of Texas who uses four-row tractor equipment and hired picking labor. Adjustments should therefore be considered in terms of subregions having at least a broad similarity of resources and production opportunities.

If cotton acreage and production in the 1928–32 period are compared with acreage and production in the years 1933–39, it is found that acreage has decreased in all areas (except the irrigated lands of the Southwest) and that production has decreased in the hilly areas west of the Mississippi, the Gulf Coast and Black Prairie Areas of Texas, and also in the western Texas and Oklahoma areas that experienced severe droughts.[3] However, higher production relative to acreage has been maintained in the Coastal Plain, the hilly areas east of the Mississippi, and in the Piedmont. In the river delta areas, production has averaged about 10% above the 1928–32 period; and in the irrigated areas of the Southwest it has averaged nearly 50% above the 1928–32 period.

Do these shifts in acreage and production give any clue to how farmers in these different areas can adjust to the prospective situation? The answer lies in the possibilities of developing alternative uses of land and labor in each of these subregions—uses that will maintain incomes to farm people. Otherwise nonfarm employment must be provided.

In the eastern hill areas it is extremely difficult to outline further adjustments in cotton production that would provide satisfactory returns without large outlays for cotton reduction payments. For example, the only alternatives to cotton that are apparent from recent farm-management studies in some of these areas are the raising of dairy replacements, feeder calves, family subsistence enterprises, and possibly large farm forest units. Further reductions in cotton acreage therefore seem highly improbable unless nonfarm employment for a part of the workers develops rapidly.

The western cotton producing areas, especially the High Plains of Texas, are another subregion in which alternatives to cotton are limited. Production of sorghums, cattle, and in some areas small grain are the best alternatives. Finishing of beef cattle with grain sorghums is practiced to some extent and adoption of a beef cattle system is

[3] "Regional Adjustments to Meet War Impacts," U. S. Dept. of Agriculture, October 1940. (Mimeographed.) See Figs. 6 and 7.

possible on some of the larger farms. Producers in this area can probably make adjustments proportional to those needed in view of cotton prospects.

The Black Waxy Prairies of Texas have been shifting toward the production of small grain, dairying, and sheep. Studies in this area indicate that farms with one-fourth to three-eighths of the crop land in cotton return a larger income than farms with a larger proportion of their land in cotton. Perhaps a further reduced cotton acreage would have less severe repercussions here than in many other sections of the Cotton Belt, and it would be consistent with the marked reduction in cultivated land needed to maintain soil resources.

The Gulf Coastal Prairie of Texas may need to maintain a higher cotton acreage than the Black Waxy area because there seems to be some opportunity for developing new farms in this area.

The Mississippi Delta is another area in which new farms are of particular importance. Farm incomes in the Delta have been the highest in the Cotton Belt. New farms are coming in each year, and it seems that the best interests of all southern farmers will be aided by fostering these possibilities as an outlet for farm families from the older sections of the South. The fertile land produces feed in abundance which makes livestock production feasible on an intensive basis. Producers in some parts of the area might shift a part of their cotton acreage to feed for livestock, but considering the development of new farms, the cotton acreage of 1938 and 1939 probably should be maintained.

Fairly good possibilities for changing the farming systems of the Coastal Plains areas, particularly in the eastern part, are seen. Income alternatives are hogs, dairying, beef cattle, vegetables, and timber. Some areas in this subregion, for example the Black Belt of Alabama, have already drastically reduced cotton production. With some assistance in shifting into other enterprises, these areas could probably adjust cotton acreage somewhat more than the national average.

In the Piedmont areas 90% of the farmers now follow a cotton-corn system, but a few farmers in the Piedmont of North and South Carolina have found it profitable to shift to fruit, beef cattle, and dairying. In addition, the industrial development in this area has provided some off-farm employment. These areas may reduce their present cotton acreages more easily than the Piedmont of Georgia and Alabama where the alternatives to cotton are subsistence, dairying, beef cattle, and woodland products. Seasonal distribution of rainfall makes the development of pastures difficult and reduces the growth of adapted legumes. Recent studies indicate, however, that farmers could reduce their cotton acreage and still maintain incomes, but the transition will have to be at a slower rate than in the Piedmont of North and South Carolina.

Farmers in the hill lands of Arkansas, Louisiana, Oklahoma, and east Texas have been faced with low cotton yields and have found it necessary to shift to dairying, small fruits, and vegetables. The farms are usually small, but the production of relatively intensive alternative enterprises, together with greater emphasis on conservation

farm plans and production for family living needs, may permit a satisfactory level of living even with a minimum of cotton.

What do some of these changes mean? What impediments retard these adjustments? The harvested crop land per capita averages about 5 acres in the eastern Cotton Belt states as compared with about 14 acres in the remainder of the United States. Thus, when a shift is made to other enterprises that require more land and less labor to obtain the same income as from cotton, we run into a scarcity of crop land. Total land resources are not quite so scarce comparatively as the present crop land. In most areas they average about one-fourth less per capita than in the Corn Belt. The central problem then becomes one of using all available land resources to provide an income for farm people, or else to find nonfarm employment for part of the population.

In some areas better care of the woodlands will bring in some cash returns—not much, but perhaps $50 per year, which is about 25% of the present income on small farms. Whether it will do this immediately depends on condition of present stands.

The acreage of food and feed crops and of pasture needs to be increased about 30% above 1939.[4] Extension workers have long advocated "live at home" programs in the South, but progress has been impeded by lack of knowledge concerning growing and handling of new products, lack of storage facilities, the lack of skill and equipment for canning and curing, and discouragement caused by prevailing credit and tenure systems.

The Farm Security Administration, in its program of financing and supervising rehabilitation clients, has found one means of overcoming some of these difficulties. Many families, however, are not reached by the FSA program. Cooperative canneries, meat curing plants, and cold storage lockers may be the answer in some situations. Technical assistance in production also is needed. The disparity between production and needs of home-used foods offers one opportunity to expand production without burdening the commercial market.

Although conditions in the old South are favorable for a relatively high degree of self-sufficiency, it must not be forgotten that some cash is needed for satisfactory living. Some farm food enterprises may develop to a point where a salable surplus is available. With a pick-up in southern industry more dairy products, more meat, and more fruit and vegetables can be sold to urban people in the South. Farmers located near army camps or close to new defense industries will benefit from these new markets.

These adjustments call for increased livestock production in the South. This means control of diseases and parasites, and above all, better yields from hay and pasture crops. Do southern research workers have the necessary answers to those problems? To a layman in that field, one of the greatest challenges in research work today appears to be the development of hay and pasture grasses that will

[4]STEANSON, OSCAR, and LANGSFORD, E. L. Food, Feed, and Southern Farms—A Study of Production in Relation to Farm Needs in the South. U. S. D. A. Bur. of Agr. Econ. November 1939. (Mimeographed.)

thrive on the poor lands of the South without requiring a greater expenditure of fertilizer than the resulting product is worth.

Southern farmers and agricultural workers are now faced with a more or less permanent situation in which cotton still returns the largest income per acre and per hour of labor but only for a part of the land and labor resources formerly devoted to cotton production. Other uses must be found for the balance of the land and labor if incomes to farm families are to be maintained.

Less cotton and more of other enterprises, especially food and feed, will result in better living for many cotton farmers. Moreover, a shift away from cotton and corn is needed in the interest of soil conservation and permanent farming. This shift requires money for fencing, pasture improvement, and for new equipment. Farmers must learn new ways of farming, and new landlord-tenant relations must be developed. The change will not be made overnight—cannot be made at all in some places without outside assistance. Livestock producers in other regions have little to fear from southern competition because farm needs and a growing urban population in the South can easily absorb all the increased production.

In areas where land resources per capita are too meager, avenues of escape into nonfarm employment must be provided. This involves education, especially vocational training for other occupations.

THE GREAT PLAINS AND PACIFIC NORTHWEST WHEAT AREAS

A continued high wheat acreage in the Plains states, despite declining export markets, points to the need for rather drastic adjustments in that region. A series of drought years that were less unfavorable to wheat than to corn and hay have encouraged wheat seedings in the eastern Plains even in the face of low wheat prices.

During the 8 years preceding 1940, wheat acreage moved eastward —a distinct reversal of the trend during the preceding 10 years. Actually the seeded acreage of wheat was maintained at or above the 1928–32 level in the western parts of the Plains, except during the driest years; but at the same time it was rapidly displacing corn in the eastern portions. The acreage of corn in the four states of North and South Dakota, Nebraska, and Kansas declined about 10 million acres, or 48% from 1932 to 1940.

The full significance of the eastward movement of wheat to replace corn is obscured by state figures because much of the shift took place within the boundaries of states. In one group of seven counties in northeast Kansas, farmers seeded three times as large an acreage to wheat in 1938 as in 1928–32. At the same time they cut the corn acreage to 60% of the normal figure. Adjustments made through the AAA program in 1939 brought wheat seedings down to double the pre-drought acreage, but the acreage of corn was still only three-fourths of the pre-drought level.

Acreage seeded to wheat in the Plains states in 1937 and 1938 exceeded by 8 million the average of the preceding 10 years. Adjustment downward in 1939 and 1940 brought the acreage seeded to 2 million below the 1927–36 average and to about 10 million acres below 1938 seedings, but in both 1939 and 1940 production of hard red

winter and spring wheats was considerably in excess of domestic needs.

With a low average yield of 10 bushels per seeded acre, seedings could be reduced about 2 million acres below the 1940 level. If wheat acreage is to be held down even to the level of 1939 and 1940, some other use must be found for about 10 million acres of land in the Great Plains. If further reduction is necessitated by export market losses, the problem becomes even greater. For most of this land feed crops and livestock production represent the only alternative use.

With favorable seasons the acreage of corn will probably increase, if not to the 1928–32 average, at least to the point where pork production would again reach the pre-drought level. An increase of, say, 6 million acres of corn over that planted in 1940 would bring the acreage to only 82% of the 1928–32 average but would supply grain enough to bring pork production to its 1928–32 level. This would represent an increase of 5 to 6% in the total United States pork production of 1939.

From the standpoint of national needs it would be better if this expansion were in beef cattle and sheep rather than in hogs. If agronomists can develop a grassland farming system for the eastern Plains that will yield as high a return to farmers as a corn-hog system, the shift might be guided toward more grass and less corn.

A return of some crop land to permanent grass is desirable in areas where crop production is uncertain. That such a change has been in progress for several years is indicated by the decrease in population in the rural counties of the western Plains. A more active public land-purchase program would facilitate this shift.

Assuming that 6 million acres would be returned to grass for beef cattle and sheep production, the increase in meat and wool would not be startling. Beef cattle numbers in 1940 in the four Plains states were only slightly below the numbers reported during the period 1928–32 but were 2.8 million below 1934. Even a shift of 6 million acres to grass would, at 15 acres a head, supply feed for only 400,000 more cattle. Probably a resumption of feed crop production at the 1928–32 level would provide for the beef produced during that period and the shifting of land from wheat plus more favorable seasons would increase numbers from the 9.1 million reported in 1940 to about 9.6 million. This would increase United States beef production by only 2.5%.

Numbers of sheep have been increasing and with an increase of feed supply some further increases could be made if sheep rather than cattle production seemed desirable.

Alternatives to wheat in the Pacific Northwest wheat areas may be even less attractive than in the Great Plains, but an increase in feed crops and livestock can be made on some farms and in particular locations. Exports of wheat from this region have depended in recent years on subsidies, and the further weakening of the export market will be felt keenly by producers. The better wheat lands will probably stay in wheat, but livestock feeding of wheat might provide a more favorable outlet than the cash market. A shift from wheat to grass or feed crops for livestock may well be encouraged on the thin and unproductive lands.

Drastic adjustments of the type discussed for the Plains and Pacific Northwest wheat areas are not made easily by farmers. New investments are involved, and where all financial reserves are depleted this means outside assistance of some kind. Federal, state, and local agencies can assist farmers remaining in these areas who still have inadequate acreage to acquire more grassland or in otherwise reorganizing their operating units. Desirable shifts in land use could be speeded and made permanent in a number of ways. The reestablishment of grass, encouraged by a program to restore abandoned crop land to permanent cover, would be stimulated through the development of a farming-grazing system in areas where migration has left room for such adjustment. This might involve organized local control of land held by disinterested absentee owners and, in some places, the incorporation of tax-delinquent land held by state or county into operating farm units. In particular instances public acquisition of land to restore its productivity and to insure conservative use of land may be desirable. Agronomists in this region can render signal service by pointing the way toward the restoration of grass cover.

Development of water resources either to insure a supply of feed or water for livestock; the financing of breeding herds on farms where feed is available and livestock numbers are low; and some method of insurance for feed crops, or provision for storing and holding feed for use in dry years, all should help to stabilize farming in the dry areas.

THE RANGE AREAS

In the range livestock areas the adjustment problem is primarily one of balancing livestock numbers with the long-term carrying capacity of the range and with the locally grown winter forage. With relatively high returns from cattle and sheep at the present time, there is real danger that ranchers may again overexpand as they did during the last war period.

From 1915 to 1919 numbers of cattle, and to a lesser extent sheep, on range lands in the 11 western states were greatly increased as a result of increasing demand, high prices, the appeal for increased production, and a liberal loan policy. Expansion in excess of the feed supply not only injured the range in particular localities but defeated its own purpose, for, with a growing scarcity of feed, losses were heavy and calf crops and gains were less than anticipated.

Overcapitalization, overdevelopment, overstocking of ranges, and overoptimism that characterized this short period (1915–19) were all tragically repeated in the late 1920's, and to some extent have plagued the western range areas almost without interruption since the last war. Bankruptcies of livestock ranches and banks throughout the range areas, deteriorated ranges, and wind and water eroded soils have brought terrific economic and social impacts to the region. Every effort should be made to avoid a repetition of these mistakes in the days ahead.

Research workers on range problems have developed much evidence to indicate that a larger immediate output from the range can be

obtained from moderate stocking than from overgrazing. This lesson needs to be brought to the attention of ranchers more effectively than it has in the past.

WESTERN FRUIT AREAS

At the present time, exports are negligible and very small exports of fruits in any form are in prospect. Recent prices to growers have been so low and costs have been relatively so high that many fruit growers are in financial distress.

The fruit industry in the western areas, because of high investment in trees of long life often on land having high water costs and necessitating an intensive type of agriculture, resists short-time adjustments. Nevertheless, in some instances it will be desirable to scale down the producing plant through the elimination of submarginal orchards. This raises questions about other intensive uses of the land that will return a living to farm families. There is need for reducing excessive debt and taxes, which farms under present price conditions cannot support. There is also need for measures that will increase the consumption of fruits. Increased efficiency both in production and in market handling is essential if even the better growers are to make a living under present price conditions.

THE CORN BELT

Considerable progress has been made in adjusting the acreage of feed grains in the Corn Belt to the decreased export demand for pork, and toward a more conserving use of land. The 1940 acreage of corn in the five principal Corn Belt states (27.4 million acres) was the lowest in 40 years. It was about 22% below the 1928-32 acreage. Oats and barley acreage also decreased, resulting in a total reduction of about 25% in the acreage of small feed grains. Wheat acreage was about the same in 1940 as in 1928–32. The acreage of soybeans for grain has increased substantially (from 0.6 million acres in 1928–32 to 4.4 million acres in 1940). The increase of soybean hay in the corresponding period was from 1.3 to 2.6 million acres. Acreage of tame hay, exclusive of soybean hay, has increased about 9%. Thus the reduction of 7.9 million acres of corn and 4.4 million acres of small grain has been offset partly by an increase of 5.7 million acres of soybeans and 1.1 million acres of tame hay other than soybean hay. The rest has largely been shifted into pasture.

Changes in feed crop production have not been proportional to changes in acreage, because of higher corn yields and a shift from mixed hay to higher yielding legume hays. If feed and hay crops are combined as feed units, the annual average production from 1938 to 1940 was 9% above the 1928–32 average. If grain, hay, and pasture are combined, the total feed units from all classes of feed averaged 10% above that in 1928–32.

A large feed supply brings pressure for increases in the livestock population. The continuing shift from horses to tractors also releases crop acreage adding to feed supplies for other livestock. The demand outlook for Corn Belt products and the need for conservation farming

point toward the desirability of further shifts away from corn and hogs and in the direction of wool, beef, dairy, and poultry products.

If it is somewhat arbitrarily assumed that conservation farming in the five Corn Belt states requires that only about 33% of the rotated land be planted to corn, soybeans, and similar crops, and somewhat less (about 28%) in small grains, a balance of nearly 40% of the rotated land would be available for hay and pasture.

Adjustments of this type would produce total feed supplies about as large as we now have, but the portion made up of hay and pasture would be much greater. That change would probably call for a considerable shift in the classes of livestock produced. Hog numbers probably would not be reduced greatly below the 10-year average of 25 million head; but beef cattle would be increased, especially those raised as feeders and grass fat beef. The increase might amount to 4 or 5% of the national production. Dairying would be increased, particularly on the smaller farms and on the borders of the Corn Belt. There would also be a further incentive toward dairying during the low price periods of the beef cattle cycle. A 4 or 5% increase in the national supply of dairy products might be expected. A small increase in sheep might also take place.

If a sufficient increase in demand for wool, beef, and dairy products is forthcoming the shifts indicated will probably result in larger immediate incomes to Corn Belt farmers. Even in instances where these changes would lower present incomes, the decrease might be more than off set by the increase in future income derived from maintaining the soil. Assistance of public programs might be needed to tide over the transition period where present incomes are reduced. Stable permanent agriculture in the Corn Belt requires that conservation farming be maintained, but further assistance might be needed to increase consumption of meat and dairy products proportionately with production. The national diet will be improved and health defense strengthened by increased use of these products.

THE LAKE STATES

Most important to the Lake states' dairyman is the expected increase in demand for butter, cheese, and concentrated milk through the general increase in consumer purchasing power and, in the case of concentrated milk, through some increase in exports. Relaxation of sanitary trade barriers for milk and cream in eastern milk markets would open up some additional demand, particularly for cream. The extent of this would depend on the elasticity of consumers' response to lower cream prices in the eastern cities. Anticipated expansion of dairying in other regions may result in some additional demand for dairy cows, and some dairymen in the Lake states may find it profitable to produce more young dairy cows instead of increasing milk production.

Even though other regions may participate in the favorable demand situation, it appears that the Lake states' dairymen can undertake a moderate expansion. As grain prices are expected to remain low relative to milk, it will probably pay many farmers to feed ad-

ditional grain per cow in addition to providing adequate supplies of improved roughage. To meet competition from other areas, it is important that production efficiency be increased as much as possible, especially in the direction of farm-produced forage and pasture.

In the last decade feed production has increased both in quantity and quality, except for interruption of drought years. There has been a marked upward trend in alfalfa acreage. These shifts, which have been given further stimulus by the agricultural conservation programs, need to be accelerated in order to provide a broad base of farm-produced feed.

THE NORTHEAST

During the 1920's when industrial activity was high, commercial farmers in the Northeast enjoyed relatively higher incomes than farmers in other areas. This resulted from the advantage of producing for nearby metropolitan markets where the purchasing power was well maintained. Industrial expansion from the defense program will probably again be reflected by rural prosperity in this region.

Technological and institutional changes that have been taking place in the Northeast during the last 20 years have induced a trend toward specialization. Market supplies are coming more and more, not from general farms, but from dairy, fruit, poultry, and potato farms. We have seen, too, the rise of large-scale bargaining, marketing, and processing organizations, and the development of various means of influencing prices and production. Perhaps the most important of these institutional developments have occurred in the handling of dairy products, particularly in connection with fluid-milk markets. Farmers' cooperatives have developed not only in the marketing field, but also in the purchasing of feeds and farm supplies.

It is undoubtedly uneconomic from the national point of view to produce large quantities of butter, cheese, and evaporated milk in the Northeast with concentrate feeds shipped from distant producing areas. Limited production may be economical as a by-product of fluid-milk production, but beyond this point the production of the relatively concentrated dairy products near the areas of feed production is a more economical use of resources.

Yet any rise in composite farm prices because of increases in class I milk prices will be likely to cause an undue expansion as the additional production will be at least temporarily profitable for the individual dairyman. As a longer time matter the choice on many Northeastern dairy farms lies between somewhat smaller production of milk based on greater self-sufficiency in feed supplies, or greater milk production based on the feeding of large quantities of grains shipped from other areas.

With the increasing specialization and commercialization of agriculture, areas of low-income farming in the Northeast have widened and have been placed at an increasing disadvantage. Part of this may be attributed to the competition with increasing efficiency of commercial farming related to technological improvements, especially modern transportation. Part is due to the failure of urban industry to furnish increased opportunities at a sufficiently rapid rate to take

care of the growing backlog of rural people. At any rate, eddies of relatively non-commercial "low pressure" farming have survived on the poorer hill lands of the Northeast. Perhaps increased activity in industry will draw labor from these areas, but the problem will not disappear, and other adjustments will be needed.

Can a "low pressure" grassland agriculture be developed—a type of livestock farming that will capitalize on summer pasture and "rough" the livestock through the winter on the low quality roughage that can be produced? Attempts to increase greatly the productivity of these lands by generous use of lime and fertilizer involve investments that "low pressure" farmers cannot afford. To realize returns on such investments requires the organization of highly commercial farms. Heavy fertilizer applications may be desirable in areas where the cropland per farm is definitely limited, but an initial expenditure of, say, $20 per acre for lime and fertilizer on large areas of $5 land surely is not an adequate answer to this problem.

OVER-ALL IMPLICATIONS

The adjustments suggested aim toward producing more products for domestic consumption; also toward shifting to products most needed in the diet of both rural and urban families. Consumption of these products may need the stimulation of programs such as the Food Stamp Plan, or variations of it, to keep pace with increased production.

In areas where land resources are entirely too limited to support the present rural population, avenues of escape should be opened up by education (especially by vocational training) and employment recruiting for the nonfarm work that may develop through the defense program. Proper safeguards are needed against creating new slums as an aftermath of the present defense emergency.

It will take several years to carry out some of the suggested adjustments. Many will require new investments, and that problem must be approached carefully because of the danger of going into debt to produce for a market that might disappear after the defense emergency is over. However, some of the more fundamental adjustments, such as shifts away from cotton and wheat and into livestock and other domestically consumed products, appear to be of permanent rather than transient character. These should be facilitated by national programs if necessary.

More research information is required to facilitate some of these adjustments. Outstanding contributions to a more permanent and more stable agriculture in this country would be made by developing hay and pasture grasses that will grow on the poor hill lands of the South and on the poorer lands of the Northeast without requiring larger expenditures for fertilizer than the value of the product will stand. Feasible and economical methods for regrassing the more hazardous crop areas of the Great Plains are also badly needed.

RELATION OF INDUSTRY TO AGRICULTURE WITH SPECIAL REFERENCE TO DEFENSE AND THE LOWER THIRD[1]

Louis H. Bean[2]

AT the outbreak of the European War in September 1939 some held the view that American farmers would profit from rising prices, from increased consumption and exports, and from the shift of surplus farm people to other industries. This view was based largely on the recollection of rising prices during the 1914–19 period that gave farmers temporarily a relatively larger share of a rising national income. But on maturer analysis it was not at all clear that the 1914–19 pattern would be reproduced. In fact, foreign markets for farm products were headed for further restriction as the war spread out over Europe and Africa and as foreign countries found it difficult to obtain dollar exchange. With the loss of export markets for cotton wheat, tobacco, pork, fruits, and other crops, the problem of surplus man power involved in our production for export, particularly in the South and Middle West, loomed larger than ever.

The obvious offset to curtailed foreign markets for farm products, some thought, would be increased domestic consumption and the migration of surplus farm labor into the war-stimulated industries. But further analysis of these possibilities suggested that domestic consumption of farm products, taking the nation as a whole, is not elastic enough to offset the loss of exports and that urban industries operating at the war-quickened rate would not even absorb all of the urban unemployed, to say nothing of making a substantial dent in surplus agricultural labor. This situation a year ago, before we really started on our defense program, logically pointed to the need for a rural works program to conserve our natural resources and at the same time to provide jobs for the excess rural man power and additional income to low-income farm families.

To some extent this situation has been altered by the inauguration of a large defense program, but this change affects and stimulates the industrial part of our economy much more than the agricultural. The defense program has already stimulated industry to the highest level on record and improved the demand for some agricultural products by increasing consumer income. It is moving some agricultural as well as urban labor into military activity and into work financed by defense expenditures. What the total effect will be we cannot yet foresee. But can it mean real improvement in the rural standard of living for a substantial number of farm people or a better distribution of income among farm families? Does it really promise to absorb surplus agricultural capacity and surplus agricultural labor, or shall we still have these twin problems to deal with?

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The course of the war, the magnitude of our defense program, the course of industrial production and prices, no one can map out with any certainty. For this occasion, we may start with one of several possible assumptions as to governmental expenditures for defense for the next two years, translate them into most probable levels of industrial activity, employment, and national income, and then consider the bearing of these on the demand for farm products, on the demand for surplus farm people, and on farm income and its distribution.

Suppose the government spends for defense purposes an additional 5 billion dollars for the fiscal year 1940–41 and 10 billion dollars for the fiscal year 1941–42. Along with this program will necessarily go an increased flow of private capital into plant and equipment in response to increased purchasing power derived from domestic and foreign orders. Together, this public and private investment will induce a marked increase in the production of durable goods. It will also bring about an increased demand and an increased production of goods for current consumption. As a result, our industrial production in 1942 may be fully 20% greater than the average for 1940. This could bring the employment of persons in nonagricultural pursuits up to 40 or 41 million, as compared with about 36 million persons employed in 1940. It could raise the national income to about 90 billion dollars, compared with 75 billion dollars for 1940.

Industrial progress of this magnitude has less promise for agriculture than one might expect at first glance. Employment now in all nonagricultural activities is practically the same as it was in 1929. It is approximately 10 million persons greater than at the bottom of the depression in March 1933. Hence, the problem of nonagricultural employment is to absorb the increase in the working population since 1929. The defense program, if it stimulates employment of 4 to 5 million additional people by 1942 will go a long way toward absorbing the urban unemployed. But it may not go the whole way, and therefore there will still remain the problem of rural unemployment, even though some rural people will be drawn by higher wages into defense jobs and defense-stimulated activities.

The exact relation of industrial employment and industrial activity to industrial opportunities for farm people can be stated only tentatively. In the first place, it is difficult to determine how many farm people and how many nonfarm people will succeed in competing for the available jobs. In the second place, our necessary bench-mark data, namely, the results of the 1940 unemployment census, are not yet available. But if we utilize our present data for what they are worth, subject to revision, we obtain this overall view of the total labor force in 1942 in industry and agriculture:

In 1942 the total labor force of the country may be about 58 million. One of several assumptions that may be made is that the employment of nonagricultural labor may amount to about 41 million persons. That would leave something like 17 million persons to be employed or accounted for in the other lines. Some 12 million working people are attached to agriculture, but not more than 9 or 10 million are needed to produce for the domestic markets and for

diminished exports.[3] Reckoning by this process of rough approximation, we shall have a national surplus labor problem of about 5 million people in 1942, in addition to say, 2,000,000 normally unemployed even in prosperity years, but now more adequately taken care of under the old-age and other social legislation. Of the 5 million, 1.5 million may need to be retained on relief work or its equivalent, 1.5 million may be inducted into military service, and about 2 million will be surplus labor in agriculture even after some withdrawal of farm people into industrial and defense programs and into military service.

If the national income approximates 90 billion dollars in 1942, compared with nearly 75 billion dollars in 1940, what is likely to be the accompanying money income of farmers? Farm cash income, with government payments, amounted to 9,000 million dollars in 1940.[4] The best appraisal that may now be made is that it may approximate 10.5 billion dollars in 1942 (including 700 million dollars of government payments), but a part of this advance could be absorbed by a rise in prices paid by farmers for goods and services. This moderate gain would yield agriculture as a whole no improvement in its share of the national income and still leave farm income about 2 billion dollars short of the parity income standard.

A greater income than 10.5 billion dollars in 1942 would have to come from one of four sources or some combination of them: Greater consumption in view of the expected increase in the national income, greater exports, higher prices, or substantially lower costs of distribution. Exports as an important source of rising farm income is not even a realistic hope for the next two years (Table 1). Exports of farm products are now down to a mere trickle. In the 1920's the export markets supplied about 16% of the total gross income from farm production and about 11% if cotton is excluded. At the greatly reduced rate of the first quarter of the 1940–41 season, the value of agricultural exports for the crop year 1940–41 may be down to only 350 million dollars, representing a farm value of probably not more than 300 million dollars or about 3% of the total gross income from farm production, or 2% of gross income excluding cotton.

The rise in farm income accompanying a rise in the national income will thus probably come chiefly through an improvement in prices in response to increased consumer purchasing power in part offset by the lower export demand. It is not likely to come from any noticeable lowering of distribution costs. It is not likely to be notice-

[3]See "How Many Farmers Do We Require" by O. V. Wells, in *Land Policy Review*, September 1940, where it is estimated that agricultural workers required for an adequate diet and nonfood products sufficient to maintain a reasonably high level of consumption for 131,000,000 people (the population estimate for 1940), together with enough commodities to meet prospective export demand are: For food, 7,800,000; for nonfood, 1,150,000; and for export, 1,050,000, a total of 10,000,000.

[4]This may be compared with 11,221 million dollars in 1929 and 4,682 million in 1932 with prices paid by farmers for goods and services lower in 1940 than in 1929. The 1940 money income from farming had a purchasing power about 80% greater than that of 1932 and about 5% greater than that of 1929, barely enough to offset the increase in the number of persons living on farms. It represented a a shortage of nearly 2 billion dollars compared with parity income.

ably increased by greater per capita consumption unless special steps, like the Food Stamp Plan, are taken to secure a net increase in per capita consumption among low-income families. A rise in the national income does not ordinarily, for various reasons, bring an increase in the national per capita consumption of foods and is not likely to do so if by 1942 our national income should go to 90 billion dollars compared with 75 billion in 1940. A few historical examples of the relative stability in per capita consumption with rising national income may be of interest.

TABLE 1.—*The share of gross income from farm production derived from the domestic and foreign markets.**

	Percentage of total gross income from production derived from		Percentage of gross income from production (excluding cotton) derived from	
	Domestic market	Foreign market	Domestic market	Foreign market
1869–73	83.4	16.6	91.3	8.7
1874–78	83.2	16.8	88.7	11.3
1879–83	80.7	19.3	85.9	14.1
1884–88	84.7	15.3	90.2	9.8
1889–93	82.4	17.6	88.1	11.9
1894–98	80.8	19.7	86.3	13.7
1899–1903	81.6	18.4	87.0	13.0
1904–08	83.3	16.7	90.1	9.9
1909–13	85.1	14.9	92.4	7.6
1914–18	82.4	17.6	86.0	14.0
1919–23	82.2	17.8	87.1	12.9
1924–28	85.3	14.7	91.3	18.7
1929–33	90.4	9.6	94.8	5.2
1934–37	91.6	8.4	95.3	4.7
1940–41 (est.)	97.0	3.0	98.0	2.0

*From "Agricultural Situation," November 1940, Table 2, page 22.

In the past 25 years we have had three periods of sharply rising national income—1914 to 1919, 1921 to 1929, and 1932 to 1939. In each of these three cases, the first year is one of depression; the other prosperity. But how much did per capita consumption change between the first and last year of each period?

In the case of cereals, our per capita consumption has been on the decline for many years and does not respond to marked advances in the national income such as we experienced between 1914 and 1919, or between 1921 and 1929, or between 1932 and 1939. In the first of these three periods, which embraces the "wheatless" days, cereal consumption per capita fell off by about 15%. In the second and third periods, the change was very slight. Average per capita consumption was smaller in the 1930's than in the 1920's in spite of the more abundant supplies. This record promises no material increase in domestic consumption of wheat and other cereals over the next two years.

Meat consumption per capita has been even more stable during periods of rising national income. For the two years in the first period, the per capita consumption of beef, pork, lamb, and poultry combined remained practically unchanged, with increased production going to Europe. For the two years in the second and third periods, meat consumption again remained unchanged.

In the case of potatoes and sweet potatoes, per capita consumption has experienced a long-time downward trend, as did cereals. It remained at about the same figure in the two years of the first period. It was again the same in 1929 as in 1921, and between 1932 and 1939 it fell off somewhat.

Butter consumption per capita has tended to fluctuate around a constant average during the past 30 years and has not been materially changed by rising national income. Fluid milk consumption per capita also fluctuated around a constant average in the 10 years prior to 1920 and after a noticeable increase during the 1920's, averaged about the same in 1932 and 1939 as in 1929. The course of consumption of poultry and eggs has duplicated that of milk. It was the same in 1919 as in 1914, increased between 1921 and 1929, and was about the same in 1932 and 1939 as in 1929.

From this record we may conclude that, with the exception of dairy and poultry products during the 1920's, none of these major groups of products showed expanded average consumption with advances in the national income such as are being anticipated for the next two years.

There are other food commodities of which the per capita consumption has showed an upward trend. These are chiefly certain fruits and truck crops and edible fats other than lard and butter. But these do not as yet bulk large in the agricultural economy as a whole. Year in, year out, the nation consumes a remarkably stable per capita quantity of food. In the entire period from 1909 to 1917, before the meatless and wheatless days, the greatest annual variation was probably only about 1%. Exactly the same order of stability in average per capita food consumption probably prevailed in the 1920's and 1930's, excluding the bad crop years of 1921 and 1934.

We may add that the one major commodity the consumption of which does respond to changes in industrial activity is cotton. In the per capita mill consumption of cotton we see reflected the major swings of the business cycle, but this does not promise any marked automatic expansion in cotton consumption over the next two years as a result of the expected rise in the national income, for the per capita consumption of cotton is already at about the maximum level. Between 1914 and 1919 cotton consumption made no net gain, but it had reached an all-time peak in 1917. Between 1921 and 1929 it was restored to about the 1919 volume, having been somewhat higher in 1927, and between 1932 and 1939 it was again restored to the 1929 and 1919 volume—where it is at present. Should it again attain the 1917 wartime peak, it would represent an additional domestic consumption of only ¾ million bales above the present rate. Such an increase would be welcomed, but it would only moderately offset the shrinkage in the export market of around 5 million bales.

There are several very important aspects of this relative stability in the per capita consumption of farm products for the nation as a whole. In large part, the relative stability in consumption of food products reflects the relative stability in food production, and it may therefore be argued that if more were produced more would be consumed. This certainly is true for certain commodities, but not for those that can be stored. Were the problem of consumption merely one of production, we would not have recurring surpluses piling up in stocks in spite of relatively low prices. It may also be pointed out correctly that during these periods of rising national income the general level of food prices also rose and thus contributed to the relative stability in food consumption. Similarly, rising costs during these periods tended to offset rising prices received by farmers and thus contributed to stability in production.

In these interrelations between national income, agricultural prices, production costs, and agricultural production, it is important to observe a very peculiar fact. Our national expenditure for food tends to be a relatively stable proportion of national consumer income. This does not mean that individual consumers, year in and year out, spend a fixed share of their income for food. But for the nation as a whole, as a result of the millions of different responses to changing prices of different foods and changing relations of food prices to other prices, we have had a fairly stable proportion of national income spent for the national food bill. This means that as more is produced and more consumed, retail prices tend to go proportionately lower but total expenditures remain relatively unchanged.

Here we touch one of the basic problems in the relation between farmer and general welfare. If more food consumption could be obtained as a result of more food production, the general welfare would presumably be served, especially if that increased consumption were among the low income groups and among those suffering from malnutrition. In the present situation it is of course even more important as a measure of defense that underconsumption and malnutrition be not allowed to continue to undermine the health of any of our citizens. But if that increased consumption involves no larger aggregate of expenditures but merely a lowering of prices to all groups of consumers, rich and poor alike, farmers would stand to lose both a reduction in gross and net returns, inasmuch as it costs more in the aggregate to process and market a larger volume, and it usually also costs more to produce it. This is the simple arithmetic of the relation between a given or stable national income, total expenditures for food, and the farmer's share.

Under conditions of the rising national income stimulated by the defense program, those relationships might not of course work out as in recent years. Much would depend on whether the volume of industrial goods for current consumption can be kept in step with the rise in consumer incomes stimulated by the production for the defense program. Stated in another way, much will depend on how the assumed increase of the national income of, say, 15 billion dollars in the next two years will be distributed as between wages and salaries and savings, and how much of what is not saved consumers will seek

to spend for farm products and for industrial goods and services. If consumers were not able to buy automobiles, houses, furniture, etc., in proportion to their increased incomes, would they pay higher prices for food and clothing or would they purchase greater quantities where these are available, or would they pay higher prices for the available industrial goods?

According to the relation of food expenditures to national income of the past decade or more, we might expect that roughly about 20% of the increase in national income might represent an increase in food expenditures, and that roughly about one-half of that might to to farmers after processing and distribution costs are deducted. In the assumed increase in the national income of 15 billion dollars over the next two years, about 3 billion would ordinarily show up in retail food expenditures and about 1.5 billion in gross income to farmers. This is one of the main considerations in our suggestion that gross farm income may not exceed 10.5 billion dollars in 1942, compared with 9 billion in 1940.

If as the national income rises and consumers obtain greater purchasing power as a result of increased employment and higher wages, and if consumer goods production lags in favor of armament production, it may be argued that price inflation might develop, and this would mean a larger gross farm income than the one we have tentatively assumed. As in 1917, 1918, and 1919, the farmer's share of the national income might be substantially increased over what it has been during the past five years. If such an improvement should come through inflation, the chances are that it would be just as short-lived and followed by losses that would more than offset the temporary gains.

Assuming no inflation, what would farm income and farm living standards in general be if food production were increased instead of being held at present levels? In view of the fact that a large volume marketed would cost more in aggregate processing and distribution costs, a good part of the assumed increase of 1.5 billion dollars in farm income might not materialize. And in view of greater aggregate production costs for the larger volume of marketings, net income for farm family living would not show the expected improvement. Thus, with increased production beyond the present volume which is sufficient for normal per capita consumption, the farmer's share of the national income would tend to decline. Furthermore, there is the additional question as to the possible rise in prices paid by farmers for industrial goods and services, the upward course of which would be determined in large measure by the course of industrial wages and the relative supply of industrial goods for non-military consumption.

What the stability of our aggregate per capita consumption and food expenditure-ratio really means is that if we want a larger national consumption of farm products among low-income people, we must have special marketing devices, such as the Food Stamp Plan, to bring it about. By this device, the purchasing power of low-income people is increased for the specific purpose of increasing their food consumption, without lowering the prices paid by consumers in the higher income brackets. Ordinarily, most of the increase in general

purchasing power goes for the purchase of industrial—not agricultural—products. In the past, our great increases in industrial production and in national income have not brought an increase in the per capita consumption of food products nor did they wipe out under-consumption among the lower third, nor malnutrition in that and other groups. We cannot expect these improvements to happen automatically now.

If we fail to make progress in increasing consumption among the lower third, the general improvement in agriculture that may take place over the next two years as a result of the defense program will not alter the living standards of the low-income farmers a great deal. It will be shared perhaps even more disproportionately than usual if we fail to improve the lot of the lower third in agriculture that has heretofore depended largely on the export markets for cotton, wheat, tobacco, and a few other products.

Ordinarily, half of all farms obtain 85% of the total gross income from farm production, and the other half receives 15%. (See Table 2.) With this kind of maldistribution of farm income, which changed very little during the 30-year interval between 1899 and 1929, most of the expected increase in farm income will go to that half of our farmers who produce the bulk of the marketed farm products. And with the loss of foreign markets hitting the South so heavily, the region of predominantly low income farms, there is even less prospect of increasing the share of the farm income of the lower third. There will still be urgent need of nonagricultural sources of income to farmers now living on a subsistence level, and of more industrial opportunities for surplus farm population. The defense program will supply the need in part, but other action will also be required. Especially is there need for more effective collaboration among farm labor and business groups to help more farmers shift from export crops to production for their own home use and more farmers to get nonfarm sources of income. Perhaps some of those now depending on

TABLE 2.—*Distribution of gross farm income in the United States, 1899 and 1929, in each of 10 equal groups of farms, arranged according to size of income.**

Group	Percentage of farms	Percentage of total gross income from farm production		
		1899	1929	Difference
1	0–10	0.8	1.1	÷0.3
2	10–20	1.9	2.3	÷0.4
3	20–30	3.3	3.0	−0.3
4	30–40	4.7	4.0	−0.7
5	40–50	5.6	5.2	−0.4
6	50–60	6.9	6.5	−0.4
7	60–70	8.9	8.9	0
8	70–80	11.8	11.5	−0.3
9	80–90	16.4	16.3	−0.1
10	90–100	39.7	41.2	÷1.5

*Derived from Census of Agriculture, 1899 and 1929.

cotton could be helped to produce for expanded food consumption among the lower third in urban and rural urban areas.

Here, too, there is maldistribution of income, and therefore underconsumption and malnutrition. In 1935–36, the lowest third among urban families had 11% of the total income available to that group and the upper third had 65%. This may be compared with about the same distribution among farm families where the lower third received 12% and the upper 62% of the income available to farm families, farm income in this case being net available for family living after deducting production expenses and including income from nonfarming sources. (See Table 3.)

TABLE 3.—*Distribution of gross income from farm production and of incomes of farm, rural nonfarm, and urban families among the lower, middle, and upper thirds.*

	Lower third, %	Middle third, %	Upper third, %	Total, %
Gross farm income 1899*	8	21	71	100
Gross farm income 1929*	8	20	72	100
Income of farm families, 1935–36†	12	26	62	100
Income of rural nonfarm families, 1935–36†	11	25	64	100
Income of urban families, 1935–36†	11	24	65	100

*Derived from Census of Agriculture 1899 and 1929.
†Based on National Resources Planning Board Estimates of Consumer Incomes.

This distribution of income among farm and nonfarm families indicates a potential market for farm products provided the lower third in each group can obtain more income. It may be argued similarly that industrial workers must have an expanded domestic market; they, too, are likely to feel a shrinkage in exports.

The farm population, greatly in need of a higher standard of living, is in effect industry's new frontier for an expanded outlet for industrial goods and services. Farmers generally can serve this purpose, however, only if they, too, have a larger income. The key to this all-round increase in buying power is increased balanced production in town and country; and since we are not confronted by any lack of farm production, the problem is basically one of more industrial activity and nonfarming occupations for surplus farm labor.

Effort in this direction would promote progress toward a more even distribution of consumer income, because it should be easier to obtain a fairer distribution of abundance than of scarcity. Yet raising the totals does not cure the trouble automatically. Between 1899 and 1929 the national income quintupled, with agriculture participating in the increase. In that period the national income advanced from about 16 billion dollars to more than 80 billion dollars. In 1899, 33% of all the farms had only 8% of the total farm income. In 1929, the lowest 33% still had only about 8% of the total farm income, though the total farm income then was much larger. At the other extreme, 10% of the farms in the highest income brackets had nearly 40% of the gross farm income in 1899, and 41% in 1929.

Apparently we need to attack the problem of income distribution and the problem of producing more income simultaneously. In the past we have been concerned more with the general rise in living standards than with a better distribution of our wealth and income. This neglect we could indulge in formerly, when land opportunities were relatively abundant and when the savings in the nation found outlets freely in new private enterprise. But our outlets for internal and external investments are no longer the automatic opportunities they used to be. Our relations to the outside world have changed so markedly in recent years that we can not depend on foreign markets any longer to serve as a sufficient outlet for our surplus labor and production capacity. In these circumstances, we can no longer wisely continue to neglect our potential markets among the lower third within our own borders.

The main object of this paper was to examine broadly what progress agriculture might make during the next two years with industrial activity stimulated by the defense program in its present form. It is conceivable, depending on the course of the war in Europe and elsewhere, that the defense effort might be altered. If it were to be stepped up, our estimates of industrial production and farm income would need to be raised and our conclusions altered with repect to the amount of surplus farm labor that might be employed.

This closer approach to a condition of full employment would, however, emphasize even more the problem of maintaining production and employment at that level and avoiding an industrial collapse and an agricultural depression after the peak of the defense program. Irrespective of the course of the defense program, we need to prepare certain industrial and agricultural props to sustain the higher level of activity. The building up of purchasing power and the living standards among the lower third in agriculture and industry is one of the necessary props, and the means for accomplishing this must be planned now simultaneously with the stimulated effects of the defense program rather than later, since the job is complex and time-consuming.

To make the lower third in agriculture and industry our new frontiers, our new markets, calls for more of the direct rather than indirect measures of increasing living standards, more of the measures that actually provide productive labor and better social and economic environments for the groups that usually get left behind. In recent years we have had three classes of proposals: (1) Those for increasing purchasing power first, such as relief payments and pensions on the theory that increased production would be bound to follow; (2) those for stimulating production first, on the ground that purchasing power would then increase more or less automatically; and (3) those that would combine the two approaches in a sort of middle-of-the-road program.

The methods of the past few years fall in the last class. They include social security and labor legislation, relief payments to unemployed and needy, benefit payments and market devices for protecting farm prices and incomes, credit and other helps to business, the use of governmental and private funds to stimulate production,

and public works to provide current employment in the creation of resources and facilities required by a growing nation.

Looking into this decade, we see the need and the opportunity for dealing more effectively with the problem of the lower third in agriculture. In addition to the activities of the Farm Security Administration, the AAA, and other agencies, there is particular need for extending social legislation in behalf of agricultural labor, for a rural works program to provide low-income farmers with supplemental employment in soil and forestry conservation work, and for a rural housing program. Direct employment and purchasing power measures of this sort for farm people and the equivalent public works and other programs for low-income people in urban areas are among the ways of converting the social and economic problems of the lower third into the new frontiers beyond the defense program.

(Since the preparation of this paper, tentative census estimates of the labor force, employment, and unemployment as of April 1940 have been released. If substantiated in the final census report, these preliminary figures suggest that the rough estimates used here may overstate somewhat the probable situation in 1942.)

ECONOMIC EFFECTS OF MORE ROUGHAGE OUTPUT IN THE CORN BELT[1]

T. W. SCHULTZ[2]

THE aim of this paper is to explore the more important economic consequences of policies designed to place more of our farm land into grasses. I propose to do this under the following headings: (a) The substitution and price effects of increased roughage output; and (b) the influence of federal programs on the production of roughages and their use.

SUBSTITUTION AND PRICE EFFECTS

A shift in the use of farm land to more roughages and less feed grains has ascertainable effects upon livestock output and consequently also upon livestock prices. Such a change in cropping practices alters the price-cost structure of feed stuffs. Roughages become cheaper relative to feed grain. How much cheaper they become is a function of two variables, i.e., the amount of land shifted from feed concentrates to roughages, and the rate of substitution of roughages for concentrates in feeding livestock.

The actual shift from feed grains to roughages is likely to be moderate, certainly within any short period of time. Farmers do not alter their cropping practices radically even when induced to do so through state and federal action programs. Furthermore, acreages transferred, for example, from corn to grasses do not reduce corn output proportionately; a 10% cut in corn acreage does not bring the output of corn down as much simply because the best land is maintained in corn and also because improvements in rotations occasioned by more grasses have a favorable subsequent effect upon corn yields which further offsets the effects of a given cut in the acreage devoted to corn. The composition of the total feed supply has not changed nearly as much as has been commonly supposed. In the Corn Belt, farmers probably will continue to produce a ratio of feed concentrates to roughages only moderately different from that of 10 or 15 years ago.

The second condition which determines the price effects of relatively larger supplies of roughages is to be found in the substitution ratios which raises the question: To what extent may roughages be substituted for concentrates in the feeding of livestock pound for pound, acre for acre? This query is essentially technical; accordingly, it is a problem for production specialists to solve, with this important proviso—what actually counts is not the rates of substitution which prevail under controlled experimental conditions, but those which exist under day-to-day actual farming conditions in the feed lots where feed is fed to livestock.

[1]Certain phases of this paper were presented before the Grassland Conference held at Ames, Iowa, September 11, 1940. Reprints of this paper are filed as Journal paper No. J-808 of the Iowa Agricultural Experiment Station.

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Theoretically, it is plain, of course, that if the substitution were perfect, represented by a straight-line relationship in which, say, a 10% increase in the acreage or amount of roughages fed, relative to the amount of concentrates, would produce the same volume of livestock outputs as would the old combination of feed stuffs with its larger proportion of concentrates, if this were true, there would be no price effects and no problem of adjustment as far as livestock production is concerned. Contrariwise, it is also plain that the substitution of roughages for concentrates would be severely limited both technically and economically if the sole outlet for feeds were in growing and fattening hogs.

Wilcox[3], in examining the rates of substitution of roughages for concentrates in feeding livestock on Iowa farms, found that, "Elasticity in the use of Iowa feeds by the different classes of livestock is sufficiently great to suggest that a ten per cent reduction in grain accompanied by a corresponding increase in hay and pasture will not, in itself, have any significant effect on the type of livestock and livestock products produced in Iowa." The range of effective substitution which is not only technically feasible but economical is apparently sufficient to permit the use of more roughages and less concentrates without curtailing or expanding any one of the several livestock enterprises. This conclusion appears to hold for most of the heart of the Corn Belt.

On individual farms, however, a shift toward more roughage is likely to occasion more feeding of the roughage-consuming types of livestock on the particular farms on which the feed is produced by feeding not only some of the corn that was formerly sold from the farm to be fed elsewhere but also by feeding the additional roughage. The chief determinant which brings this development about is the low specific value of roughage, which makes it costly to transport it to other farms to be processed into livestock; and, since corn is also complementary to roughages, more corn is also likely to be held back and fed.

There are several obstacles to the normal development of this adjustment. The tenure situation discourages the roughage-consuming livestock enterprises. Credit institutions ration the amount of capital which operators may obtain, thus checking investments necessary to a roughage economy.

We conclude, therefore, that the price effects of producing more roughages and less feed grains within the moderate limits likely to be attained in, say, 10 years are not likely to influence appreciably the type or volume of livestock produced in the Corn Belt. Consequently, programs which accomplish this end are in themselves not likely to have any measurable effects upon the relative prices of the livestock and livestock products.[4]

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[3]Wilcox, Walter W. Livestock production in Iowa as related to hay and pasture. Iowa Agr. Exp. Sta. Bul. 361. 1937.

[4]Quality of livestock produced may be improved by the availability of a better combination of feedstuffs.

INFLUENCE OF FEDERAL AGRICULTURAL PROGRAMS

The federal agricultural action programs may, for the purpose of this paper, be classified according to those features which (a) ration the use of farm land, (b) alter relative prices of farm commodities, or (c) increase the consumption of selected farm commodities. The direction and extent to which each of these features has a bearing upon the production and use of roughages in the Corn Belt will be outlined briefly.

In the first of these, crop acreage control, the AAA and the SCS have in their respective programs induced farmers to reduce their corn, oats, and barley acreages and to increase the amount of farm land devoted to grasses and hays. Obviously, such programs if pushed far enough must affect the type and volume of the available feed supplies. The broad outlines of what has happened are plain (Table 1). Farmers have changed their cropping practices as follows: Corn acreage in the six central Corn Belt states dropped to 32 million acres in 1940 compared to 39 million during 1928–32, a drop of 19%. Not all of this cut is ascribable to the efforts of the AAA and SCS. Drought condition in the Plains states, for example, has forced upon South Dakota, Nebraska, and Kansas a much greater cut in corn, down 46%. In the central and eastern Corn Belt states, especially in Iowa, Illinois, and Indiana, soybean acreage has shot up enough to offset in large measure both the conservation and reduction in concentrate feeds resulting from fewer acres in corn. The change in oats has been downward but relatively less so than with corn; in the main this is a continuation of a long-time decline which has been in process for two decades, while the acreage given to barley has stayed about the same, with the acreage in hays up slightly.

TABLE 1.—*Corn production and acreage adjustments.*

Region	1928–32 average	1937–39 average	1940	1937–39 in % of 1928–32	1940 in % of 1928–32
		Acreage*			
United States	103	92	86	89	84
6 central Corn Belt states†	39	36	32	92	81
3 western Corn Belt states‡	21	13	12	60	54
		Production*			
United States	2,555	2,611	2,352	102	92
6 central Corn Belt states†	1,345	1,571	1,267	117	94
3 western Corn Belt states‡	432	170	195	40	45

*000,000 omitted. Estimates production data taken from U. S. D. A. general crop report, October 1; acreage data taken from "Crops and Markets" for August.
†Iowa, Illinois, Indiana, Minnesota, Ohio, and Missouri.
‡Nebraska, Kansas, and South Dakota.

Somewhat more precise and adequate data are available for Iowa in the studies of Wilcox and Crickman.[5] In 1940, Iowa farmers had

[5]Summary reports of these studies have been published in the *Iowa Farm Economist*. Iowa Agricultural Extension Service and Iowa Agricultural Experiment Station jointly.

23% less acreage in corn, but only 11% less in intertilled crops and 23% more in soil-conserving crops than they had during the period 1929–33.[6] It is noteworthy that this change in the cropping practices in the state was achieved although a fourth of the Iowa farmers were not participating in the program of the AAA in 1940. This shift in acreages, however, substantially overstates the change that has occurred in the available feed supply. Several factors have operated to offset changes in the proportion of roughages to concentrates which the shift in acreage would appear to have occasioned. The improvement in rotation, the use of better seeds, better cultivation, the maintaining of the most productive land on the farm in corn, along with exceptional corn-producing seasons have increased the per acre yield of corn to offset the reduction in corn acreage. It is true, however, that as a result of the programs, more and a higher quality of roughage have become available throughout much of the Corn Belt.

The sum and substance is about as follows: *the rationing of the use of farm land in the Corn Belt on the part of the AAA and SCS has not thus far changed the type or the volume of the feed supply enough to affect appreciably the production of livestock with the minor qualification that on some farms where formerly the supply of high-quality roughage was so limited as to be a critical limiting factor, the increase of it has probably given increasing returns.* The experience of crop control with feed grains and roughages to date points to the conclusion that governmental programs designed to ration the use to which farm land in the Corn Belt is put are not likely to influence livestock production unless much more drastic rationing is undertaken. This is merely another way of saying that in the agriculture of this region there is inherent a great deal of flexibility which permits farmers to offset rather fully the effect of holding any one factor of production in check.

The second category of program features takes in those which alter relative prices of farm products. The primary instrument for accomplishing this aim, as far as Corn Belt farm products are concerned, has been accomplished through loans and storages. Here again it is not necessary to describe the operations of these loans and the conditions under which they have been made except to note that in recent years the practice of sealing corn has added a substantial price premium to corn relative to what the price would have been had a smaller volume of carry-over been accumulated.

The corn loans have been sufficiently high relative to the price of other feed concentrates and to the prices of roughages generally, especially in the western part of the Corn Belt, to have occasioned a considerable amount of substitution for corn of oats, barley, and, in some sections, of low-grade wheat and also of rye and especially of processed feed concentrates such as the mill feeds. Because of the fairly ample supplies of these feed concentrate substitutes, the incidence of the substitution has favored roughages less than would otherwise have been the case; nevertheless, the corn loans have

[6]These figures overstate to some extent the actual change that has occurred because the base figures are by the nature in which they were obtained somewhat "inflated" for corn and too low for conserving crops.

probably induced a considerable expansion in the use of roughages. To put it the other way around, instead of roughages going cheap in order to induce their use, corn has been held relatively high, the effect of the latter is the same as that of the former, as far as relative prices are concerned in inducing the use of roughages.

It should not be overlooked, however, that this additional demand for roughages, as well as that of feed concentrates other than corn, which has been brought about by the relative high corn loans has been bought at a "price" which appears on the books in the form of large stocks of unused corn. We have accumulated a carry-over considerably in excess of what was contemplated for ever-normal granary purposes. To put it still another way, if we seal up most of our feed concentrates, this action will create a large additional demand for roughages as feed for livestock. To a limited extent the corn loans have worked in this direction mainly in the western part of the Corn Belt.

The third and last class of influences ascribable to features of governmental action programs to be taken up in this paper are those which have their roots in the subsidization of consumption of farm products. The most significant of these is the Food Stamp Plan. Recent studies suggest that those consumers who have been given financial assistance through this plan are likely to allocate more of their recently acquired purchasing power to those farm products which require grasses to produce, such as meats and dairy products, rather than shifting their additional buying power to cereals. While the basic principles which underlie the Stamp Plan have a great deal of merit as means for improving the nutrition and health of low-income families, the net effect of the present programs upon the relative prices of farm products has undoubtedly been quite small. Several reasons account for this. The number of the families which are now served by this Plan are only a fraction of all low-income families. Consumers are allowed a considerable range of choice in the use of the additional purchasing power which the Stamp Plan gives them. The importance of distribution costs in the price of the final product is also of import. For these and other reasons it appears likely that the Food Stamp Plan[7] in itself is not likely soon to have much effect upon the relative prices of farm products. Supplementary income to consumers via the Stamp Plan is not likely to influence the production of livestock and livestock products appreciably and hence has little measurable bearing upon the use of feed supplies and conservation.

There is a considerable body of opinion in this country to the effect that the federal government should subsidize, on a large scale, the consumption of dairy products. The reasons advanced for such a policy have been that it would not only tend to correct deficiencies in diet but it would also facilitate conservation efforts by inducing farmers to grow more grasses and roughages. Would it, however, accomplish the latter aim? To the extent that the analysis of this paper is upheld by subsequent experiences and studies, i.e., that the

[7]A comprehensive analysis of the Food Stamp Plan is presented in a forthcoming publication of the U. S. Dept. of Agriculture which has been made by Dr. F. V. Waugh and his colleagues.

effective substitution of roughages for feed grains is exceedingly elastic, it follows that when the prices of dairy products rise relative to other livestock products, the output of dairy products will be expanded and other types of livestock products curtailed using the same feed supply. This being true, a moderate or even marked expansion in dairying in this country will not necessarily place a premium upon roughages as against concentrate feeds.

Thus, we conclude that programs which subsidize dairy consumption, even on a grand scale, need not necessarily have the effect of motivating farmers in the Corn Belt to produce more grasses and less feed grains as proponents of that policy have claimed.[8]

[8]In Iowa the production of creamery butter more than doubled during the twenties, while the farm land devoted to hay and pasture declined appreciably. The expansion in dairy products was a response to a change in relative prices which tended to make dairy products more profitable than alternative livestock enterprises and the shift toward more dairying was actually made while acreages in hay and pasture were reduced.

SEED COVER AND PLANT COLOR AND THEIR INTERRELATIONS WITH LINT AND SEED IN UPLAND COTTON[1]

J. O. WARE[2]

THE density of seed cover in cotton or the degree to which the seed coat bears short fuzz fiber is of interest to the geneticist as well as to the plant breeder. Fuzz presence or absence has an important bearing on lint production and the amount and length of fuzz are factors in processing and in manufacture. The size of seeds and the covering affect the rate and regularity of planting and influence germination, and the weight of seeds alters lint percentage. Plant color may be a factor in production in that repellent effects on certain insects seem to be associated with red plant color and in that the appearance of anthocyanin can be used as a marker in identifying plants from useful hybrid combinations.

The inheritance of seed cover in upland cotton (*Gossypium hirsutum*) has been studied by Thadani (10)[3], Kearney and Harrison (7), Carver (1), Griffee and Ligon (3), and Winters, *et al.* (17), all of whom found it to behave as a monohybrid character with three plants having naked seeds to one having covered seeds in the F_2. In a subsequent review, Kearney (6) first pointed out the existence of two sorts of naked seeds and described the two classes but presented no data. Richmond, Harper, and Beasley (8) have reported (without data) three stages of the fuzz covering and pointed out the lint relationship to these three classes. Ware (15) supplied results that demonstrate the modified monohybrid ratio for seed cover and has designated the F_2 classes as fuzzy (covered), naked-adherent,[4] and naked. These classes occur in the 1:2:1 ratio.

Jenkins, Hall, and Ware (5) have recently reported a study of seed cover as related to leaf shape in upland cotton. In this work each of the three classes, fuzzy, naked-adherent, and naked, in turn were broken down further into subclasses or grades. Degrees of fuzziness or pattern of fuzz of the seed coat in the fuzzy class and variation in the number of lint fiber stubs attached to the seed coats of the two nonfuzzy classes provide the basis for assignment of numerical grades. Ware (16) has further described and illustrated the seed grades. The range used is from 1 to 20. The first 10 grades (1 to 10) embrace the fuzzy class and vary from a very heavy fuzz mat to a bald body with a fuzz brush at the small or hilum end of the seed. The naked-adherent class includes four grades (13 to 16) and the naked class, two grades (18 and 19). Grades 11 and 12 are transitional stages between fuzzy and naked-adherent; grade 17 a transitional stage between naked-adherent and naked; and grade 20 an ideal stage above naked and representing complete

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[3]Figures in parenthesis refer to "Literature Cited", p. 435.

[4]The seeds in this new class are free of fuzz but have the basal section of a portion of the lint fibers adhering to them and giving them an appearance of downy ciliation by means of which the class is identified.

fuzz and lint absence. Usually, very few plants appear that possess seed cover characteristics corresponding to any of these extra-grade stages. When such are found, placement is made in the class group most nearly resembling the particular case. In the work reported by Jenkins, Hall, and Ware (5), and in the present work, some F_2 segregates occurred in grade 17 but were placed in the intermediate or naked-adherent class. From the standpoint of appearance grade 17 is very close to grade 16, the last true naked-adherent grade.

Thadani (11) reported three seed cover patterns "wooly," "felted," and "scanty." Grades 3, 5, and 7 used here correspond to Thadani's classes. In his F_1, naked seeds were dominant to each of the three fuzzy forms and likewise both felted and scanty were dominant to wooly, that is, seeds devoid of fuzz were dominant to those with fuzz, and those with less fuzz were dominant to those with more fuzz. Thadani did not report F_2 data which would have provided information on the degree of stability of the type of seed cover pattern he isolated.

Winters, *et al.* (17) and Carver (1) studied the inheritance of a strain having the fuzz confined to the hilum end of the seeds. This seed cover pattern was designated as "fuzzy tip" and corresponds to grade 9 or 10 in the present work. Fuzzy tip is dominant to full cover, but when crossed with a naked seed type the F_2 produced a 12:3:1 ratio of naked, fuzzy tip, and fuzz covered seeds. In this connection, Carver stated that the fuzzy tip character is fundamental as a distinction between the fuzzy and naked classes[5] and suggested that the presence of fuzz over the seed coat may be controlled by modifying factors.

The mode of inheritance of red plant color in upland cotton has been known for some time and has been reported or reviewed by Ware (12, 13, 14), Kearney (6), Harland (4), and others. These reports show that the character is monohybrid, the F_2 segregating into the 1:2:1 ratio of red, intermediate red, and green plant colors. Carver (1) reported independent inheritance of red plant color and naked seeds. In Carver's work only 124 F_2 plants were used. Definite seed patterns were not established nor were lint and seed weights taken into consideration. The present work provides a larger number of plants for testing independence of inheritance of seed cover and plant color, and also supplies, in association with the plant color segregates, data pertaining to seed cover patterns or grades, lint index, seed index, and lint percentage.[6]

MATERIAL AND METHODS

Two plants from different lines of a red or the Winesap variety and two plants from the same line of the No Lint variety[7] were selected as parental material and two crosses made between the two contrasting pairs. The two Winesap plants differed principally in degree of seed cover. One of these had seeds completely covered with fuzz but in a thinner mat than persists in grades 1 to 3 of the scale of grade standards heretofore cited. The seed cover of this plant approximated

[5]Carver's work was published before Kearney's separation of the naked seed group into two classes.

[6]Lint index is the weight in grams of lint from 100 seeds; seed index is the weight in grams of 100 seeds; and lint percentage is the weight of lint expressed as a percentage of the weight of the seeds plus the lint, or of the weight of the unginned cotton.

[7]The four plants were pure for plant color and were highly homozygous apparently for their seed cover grades, levels of lint production, and weight of seeds. Each had been inbred and selected, the Winesap lines for 5 years and the No Lint line for 4 years.

Thadani's felted but was classed as grade 4.[8] The group of plants including the F_1 and F_2 generations from the cross of this plant with one of the No Lint plants is designated as cross I. The other Winesap plant had seeds only partly covered with fuzz but with a prominent fuzz brush on the hilum end. The seed cover of this plant was identical with Thadani's scanty and was classed as grade 7. The cross of this red plant with the second No Lint plant and including their hybrid progenies is designated as cross II. Both Winesap plants produced a normal amount of lint or a percentage at the level of about 34.5. The No Lint plants had normal green plant color, sparse lint at approximately a level of 6 to 7%, and naked seeds. The seeds of both No Lint plants were classed as grade 19.

Seeds were obtained from each of the four parental plants and progenies were grown from each for checking the purity of the parents and to obtain seed and lint data for comparison with similar data collected from the F_1 and F_2 hybrid generations. Twelve F_1 plants of cross I and 10 F_1 plants of cross II were propagated in separate groups for the production of F_2 seeds. The F_2 progenies of these 22 different F_1 plants were grown and separate chi-square tests were made utilizing the method given by Fisher (2) for this purpose. In each progeny the three-class segregations for seed cover and the three-class segregations for plant color were tested singly and then together as dihybrid segregations. Likewise, the total F_2 population of cross I and the total F_2 population of cross II each received the same application of the test as the individual progenies.

The F_2 lint index, seed index, and lint percentage values are stratified according to the seed cover classes and subclasses or seed grades, and according to the plant color classes. The 12 progenies of cross I were combined in one group and the 10 progenies of cross II in another. The lint index, seed index, and lint percentage values in these stratified groups are represented by the weighted mean. The corresponding parental and F_1 data are set up also with these two groups to facilitate the parental and offspring comparisons. Since the plant frequency number, constituting the means in the several groups, varied, Snedecor's (9) method for comparing means of such composition was utilized. By this method the significance of the differences among or between the several F_2 classes and grades was determined respectively for the three variables.

RESULTS

The results obtained are presented in Tables 1, 2, 3, and 4. A summary of the chi-square tests appears in Table 1. In this table the chi-square values are tabulated for the separate F_2 progenies in frequencies on the probability scale. Also, in the rightmost column the probability values for the two populations as groups are shown. The number of plants in each class or grade and their lint index, seed index, and lint percentage means are given for cross I in Table 2 and for cross II in Table 3. The corresponding parental and F_1 values also appear in these tables. The F values included in this report are given in Table 4, those for cross I appearing to the left and those for cross II to the right of the table. These values were not computed for differences among the parents and the F_1. The mean differences for lint index and for lint percentage among these plant groups were pronounced and obviously significant. On the other hand, the seed

[8]It will be noted later that the progeny of this plant split between grades 4 and 5. The latter simulates the felted.

index difference between parents in both crosses was quite small and, therefore, the contrast is of little value for inheritance study. The F values for the three-variable grade differences within the F_2 fuzzy class, although computed in both crosses, are not reported in Table 4 as groups.[9] The mean differences were insignificant except in a very few cases. Such exceptions are noted in the appropriate sections of discussion below.

SEED COVER

In the F_2 of cross I and of cross II and in recent work of Jenkins, Hall, and Ware (5) and of Ware (16), both parental and the F_1 seed grade type are recapitulated, one grade occurring respectively in each of the three seed cover classes, *viz.*, fuzzy, naked-adherent, and naked. Also, in the former and present studies, additional seed grades representing variation or modified seed cover patterns appear in each of the three seed cover classes.

The seed cover grades of the progenies of each of the four parental plants indicate rather high stability for the particular grades in the parental material. The 22 plants grown from the Winesap plant classed as grade 4 fluctuated between grades 4 and 5, and the 17 plants grown from the Winesap plant classed as grade 7 varied between grades 7 and 8. Each of the 56 plants from the No Lint plant used in cross I and the 13 plants from the No Lint plant used in cross II showed no seed grade variation. The seed grade of these 69 plants was identical with the parents, grade 19. The two Winesap plants as measured by their progenies on the scale of seed cover grades show evidence of belonging to different distributions. A gap of one grade occurs between the two populations. This difference in seed grade between the two red stocks, on the other hand, had only slight differential effect on the two crosses which the red plants entered. Both F_2 distributions range from grade 4 to grade 10 in the fuzzy class, occupy grades 15, 16, and 17 in the naked-adherent class, and grades 18 and 19 in the naked class. Also, the plant frequencies in the corresponding F_2 grades of cross I and cross II are similar, except that in the former group 76.8% of the plants of the fuzzy class appear in grades 7, 8, 9, and 10, while in the latter group 82.2% of the plants occur in these four grades of the fuzzy class. It likewise follows that the group having the higher percentage of plants with the thinner fuzz in the F_2 fuzzy class is the cross with the red plant that had seeds classed as grade 7. While the two F_2 progenies vary only to this degree in seed cover between themselves (in spite of the pronounced variation in grade between the fuzzy parents), both have many more thin fuzz segregates than are found when plants having heavier mats of seed fuzz (grade 2 or 3) are crossed with naked seeded plants. In the F_2 of the cross between a plant having seeds classed as grade 3 and a No Lint plant, reported by Ware (16), only 9.5% of the plants of the fuzzy class occurred in grades 7, 8, 9, and 10. Jenkins, Hall, and Ware (5), in a cross which involved a fuzzy seeded plant having seeds classed as grade 2 and a No Lint plant, did not obtain any segregates in the F_2 fuzzy class having seeds classed above grade 6. Also, in the

[9]Table 4 already being large, the less essenti[illegible]ted.

TABLE 1.—*Chi-square tests of the 22 F_2 segregating progenies for plant color, for seed cover, and for both characters combined of crosses I and II, No Lint × Winesap.*

Classes	Ratio	Distribution for progenies in the P scale												All progenies, P
		0.98	0.95	0.90	0.80	0.70	0.50	0.30	0.20	0.10	0.05	0.02	0.01	
							Cross I*							
Plant color[1]	1:2:1	—	—	2	2	2	2	—	1	2	1	—	—	0.02−
Plant color[2]	3:1	—	—	—	—	—	—	—	—	—	—	—	—	0.99−
Seed cover[3]	1:2:1	—	1	1	1	—	3	1	2	3	—	—	—	0.90−
Plant color and seed cover[4]	1:2:1:2:4:2:1:2:1	—	—	1	1	3	1	3	1	2	—	—	—	0.20+
							Cross II†							
Plant color[1]	1:2:1	—	—	—	—	2	1	2	—	4	1	—	—	0.01−
Plant color[2]	3:1	—	—	—	—	—	—	—	—	—	—	—	—	0.70−
Seed cover[3]	1:2:1	—	—	1	3	2	—	—	2	2	—	—	—	0.70+
Plant color and seed cover[4]	1:2:1:2:4:2:1:2:1	1	—	—	—	2	4	—	2	1	—	—	—	0.01−
All for seed cover[5]	3:1	—	—	—	—	—	—	—	—	—	—	—	—	0.50+
Plant color and seed cover[6]	9:3:3:1	—	—	—	—	—	—	—	—	—	—	—	—	0.80+

*Twelve progenies, totaling 1,502 plants.
†Ten progenies, totaling 1,177 plants.
[1]Red = RR, Intermediate Red = Rr, Green = rr
[2]Red and Intermediate Red = RR, Green = rr
[3]Naked = NN, Naked-Adherent = Nn, Fuzzy = nn
[4]RRNN, RRNn, RRnn, RrNN, RrNn, Rrnn, rrNN, rrNn, rrnn
[5]Naked and Naked-Adherent = NN, Fuzzy = nn
[6]RRNN, RRnn, rrNN, rrnn

F_2 fuzzy class of these two previous studies, segregates were obtained with seeds more densely covered with fuzz than in the corresponding class of cross I and cross II. The seed cover of these segregates was classed as grade 2 and grade 3, while the heaviest seed cover occurring in the present work, as heretofore noted, is not lower than grade 4.

Considering the previous data concerned with seed cover grades, together with the current study, crosses involving grades 2, 3, 4, and 7, respectively, with grade 19 of the No Lint stock are available for comparison. These results considered as a whole show two types of behavior, first, an upward shift in grade distribution of the F_2 fuzzy class as plants with thinner fuzz are used for the fuzzy parent and, second, a build-up of plant frequencies in two zones in this distribution after parents having the thin fuzz are used.

In the data of Ware (16) and of Jenkins, Hall, and Ware (5) where fuzzy parents of grades 2 and 3 entered the crosses, the plant frequency curves for the F_2 fuzzy grades are distinctly monomodal with a small sharp "tail" of skewness toward the thinner grades. On the other hand, in the F_2 fuzzy classes of cross I and cross II, the plant frequencies of the fuzzy grades are bimodal with one peak around grades 4 and 5 and the other around grade 9. It appears here, therefore, that there is a tendency to form two classes—the fuzzy class and the fuzzy tip class. Had one of the Winesap plants been of grade 9 or 10 instead of 4 or 7, more pronounced segregation may have occurred as Winters, *et al.* (17) and Carver (1) found when they crossed fuzzy tip and naked seed types and obtained two discontinuous classes within the fuzzy group.

Where the fuzzy seeded parent (grades 2 or 3) had a heavier mat of fuzz, more lint basal attachments appeared in the F_1 generation, and segregation into more grades occurred in the naked-adherent F_2 generation than when the fuzzy seeded parent had thin fuzz (grades 4 or 7). In the work of Jenkins, Hall, and Ware (5) where the fuzzy seeded parental strain was classed as grades 2 to 3, the F_1 generation varied between grades 15 and 16 and the F_2 naked-adherent class segregated into grades 14, 15, 16, and 17. In the work of Ware (16) where the fuzzy seeded parental strain was classed as grade 3, the F_1 fell into grade 15 and the F_2 naked-adherent class broke up into grades 14, 15, and 16. In the present work the seed grade of both F_1 groups was classed as grade 16 and the F_2 naked-adherent class separated into grades 15, 16, and 17. The naked F_2 class of these cited reports and in the present work contained two seed grades, grades 18 and 19.

While the range of the seed cover grades was further up the scale in the F_2 fuzzy classes of cross I and cross II than in the same classes of previously cited studies, and while the F_2 frequency distribution for fuzzy tended to be bimodal in the present work and monomodal in the previous work, the fuzzy class as a whole behaved in all cases as a monohybrid class with respect to the other two classes, naked-adherent and naked. The segregation of the fuzzy (grades 4 to 10 inclusive), the naked-adherent (grades 15, 16, and 17), and the naked (grades 18 and 19) classes of the F_2 of both cross I and cross II into the 1:2:1 ratio is as clearcut as in the crosses where plants having

TABLE 2.—*Lint index, seed index, and lint percentage means of parental strains, and F_1 and F_2 generations of cross I, No Lint × Winesap, wi h the F_2 data stratified in accordance with plant color and seed cover segregations.*

Seed cover grade	Number of plants	Lint index	Seed index	Lint percentage	Number of plants	Lint index	Seed index	Lint percentage	Number of plants	Lint index	Seed index	Lint percentage	Number of plants	Lint index	Seed index	Lint percentage
	Parental Strains and F_1															
	No lint parent, seed cover grade 19				F_1, seed cover grade 16				Winesap parent, seed cover grades 4 and 5							
	56	0.64	8.92	6.7	39	3.05	9.70	23.9	22	5.35	10.17	34.5	—	—	—	—
	F_2 Generation															
	Red plant color class				Intermediate red plant color class				Green plant color class				Three color classes combined			
	1. Fuzzy Seed Class															
4	7	4.80	10.04	32.2	18	4.56	10.04	31.2	11	4.72	10.04	32.1	36	4.66	10.04	31.7
5	3	4.20	8.80	32.1	17	4.65	9.55	32.8	13	4.78	9.55	33.5	33	4.66	9.48	33.0
6	1	5.23	9.00	36.8	9	4.42	9.06	32.9	6	4.69	9.06	34.2	16	4.57	9.06	33.6
7	1	4.52	9.05	33.3	2	4.24	7.99	34.9	1	4.21	8.71	32.6	4	4.30	8.43	33.9
8	14	4.55	9.45	32.5	30	4.50	9.28	32.7	13	4.33	9.14	32.1	57	4.47	9.29	32.5
9	30	4.42	9.07	32.7	91	4.40	8.86	33.2	39	4.37	9.15	32.3	160	4.40	8.97	32.9
10	17	4.34	9.05	32.4	29	4.50	9.40	32.5	15	4.51	9.42	32.5	61	4.46	9.30	32.5
All	73	4.47	9.22	32.6	196	4.47	9.17	32.8	98	4.50	9.33	32.6	367	4.47	9.23	32.7
	2. Naked-Adherent Seed Class															
15	25	2.74	8.59	24.2	54	2.81	8.87	24.1	28	2.77	8.73	24.1	107	2.78	8.77	24.1
16	124	2.65	9.14	22.4	308	2.59	9.04	22.2	152	2.64	9.07	22.5	584	2.61	9.07	22.4
17	22	2.31	9.33	19.8	32	2.43	9.35	20.6	15	2.52	9.54	20.8	69	2.41	9.39	20.4
All	171	2.62	9.08	22.3	394	2.60	9.04	22.4	195	2.65	9.05	22.6	760	2.62	9.05	22.4
	3. Naked Seed Class															
18	3	0.20	8.71	2.3	4	0.26	9.07	2.8	3	0.16	9.55	1.6	10	0.21	9.11	2.3
19	82	0.32	9.01	3.4	200	0.29	9.00	3.1	83	0.26	8.90	2.8	365	0.29	8.98	3.1
All	85	0.31	9.00	3.4	204	0.29	9.01	3.1	86	0.25	8.93	2.8	375	0.29	8.99	3.1
	4. Three Seed Classes Combined															
All F_2	329	2.43	9.09	19.7	794	2.47	9.06	20.0	379	2.58	9.10	20.7	1,502	2.49	9.08	20.1

seed cover grades of 2 or 3 were used. The 1,502 F_2 plants of cross I, as shown in the right-hand section of Table 2, were classed into 367 fuzzy seeded, 760 naked-adherent seeded, and 375 naked seeded. Likewise, the 1,177 F_2 plants of cross II, as shown in the right-hand section of Table 3, segregated into 303 fuzzy seeded, 591 naked-adherent seeded, and 283 naked seeded. Both distributions correspond closely to expected numbers as indicated in Table 1 by the probability value of approximately 0.90 for the former and slightly over 0.70 for the latter. The chi-square tests as applied to the 12 individual F_2 progenies of cross I demonstrate a probability range of 0.95 to 0.10 and as applied to the 10 F_2 progenies of cross II showed a range in probability from 0.90 to 0.10.

PLANT COLOR

The chi-square tests of the 22 progenies of the F_2 of cross I and cross II when applied singly showed all segregations for plant color to correspond satisfactorily with expected numbers. As shown in Table 1, the 22 probability values range from 0.90 to 0.05 with a large portion of these values relatively high on the probability scale. On the other hand, when the total F_2 distributions of the two crosses were tested, minor deviations in some of the smaller groups were accumulative which caused wide deviations between observed and expected numbers when the larger groups were involved. The probability values of both groups were below the 0.05 level. After the red and intermediate red classes of these larger groups were combined and the ratio placed on the 3:1 basis for all red plants, as contrasted with green plants, the goodness of fit tests were again highly satisfactory. The probability value of cross I approached 0.99 and that of cross II approximated 0.70.

SEED COVER AND PLANT COLOR

The two characters seed cover and plant color, when operating together, segregate into nine classes. The chi-square tests for independence of inheritance in these dihybrid ratios are made on the basis of the nine classes and also on the regular four-class basis when deviations in the former distribution cause an unsatisfactory result. The ratio bases and the probability values obtained are shown in Table 1.

The 22 F_2 progenies when tested singly were each found to have class numbers corresponding satisfactorily with the expected modified dihybrid number. The probability values ranged from 0.98 to 0.10. The 1,502 F_2 plants of cross I when distributed among the nine classes showed a satisfactory test, having a probability value of a little over 0.20. On the other hand, the 1,177 F_2 plants of cross II when likewise distributed did not correspond closely to the expected number, the probability value being below 0.01. In this group, plant color on the 1:2:1 basis exhibited more deviation than in cross I and, therefore, is accountable for the unsatisfactory result in the modified dihybrid distribution. When the two red color classes and the two fuzzless classes are combined and the ratio placed on the 9:3:3:1 basis, the

TABLE 3.—*Lint index, seed index, and lint percentage means of parental strains and, F_1 and F_2 generations of cross II, No Lint × Winesap, with the F_2 data stratified in accordance with plant color and seed cover segregations.*

Seed cover grade	Number of plants	Lint index	Seed index	Lint percentage	Number of plants	Lint index	Seed index	Lint percentage	Number of plants	Lint index	Seed index	Lint percentage	Number of plants	Lint index	Seed index	Lint percentage
	Parental Strains and F_1															
	No Lint parent seed cover grade 19				F_1, seed cover grade 16				Winesap parent, seed cover grades 7 and 8							
	13	0.76	9.39	7.6	21	3.37	9.55	26.2	17	5.04	9.62	34.4	—	—	—	—
	F_2 Generation															
	Red plant color class				Intermediate red plant color class				Green plant color class				Three color classes combined			
	1. Fuzzy Seed Class															
4	1	4.49	9.74	31.6	7	4.47	8.74	33.8	3	4.68	9.99	31.9	11	4.53	9.17	33.1
5	9	4.58	9.01	33.9	14	4.44	8.38	34.6	7	4.72	9.01	34.4	30	4.55	8.72	34.4
6	1	4.81	8.75	35.5	8	4.78	9.38	33.7	4	4.14	8.18	33.3	13	4.59	8.97	33.7
7	5	4.47	8.57	34.4	8	5.22	9.99	34.4	6	4.43	8.18	35.3	19	4.77	9.05	34.7
8	18	4.54	8.61	34.5	41	4.67	8.70	35.0	20	4.49	8.63	34.2	79	4.59	8.66	34.7
9	23	4.64	8.57	35.1	71	4.55	8.60	34.5	29	4.76	9.07	34.4	123	4.61	8.70	34.6
10	5	5.12	8.54	37.5	15	4.67	9.06	34.1	8	4.84	9.14	34.8	28	4.80	8.99	34.9
All	62	4.63	8.66	34.9	164	4.62	8.76	34.5	77	4.63	8.88	34.3	303	4.62	8.77	34.5
	2. Naked-Adherent Seed Class															
15	21	2.93	7.76	27.4	69	3.27	8.61	27.6	42	3.25	8.45	27.8	132	3.21	8.42	27.6
16	90	3.14	8.81	26.3	237	3.14	8.80	26.4	103	3.13	8.96	25.8	430	3.14	8.84	26.2
17	5	2.65	9.33	22.1	17	2.76	9.41	22.4	7	2.89	10.06	22.0	29	2.77	9.55	22.2
All	116	3.08	8.64	26.3	323	3.15	8.79	26.4	152	3.15	8.87	26.2	591	3.14	8.78	26.3
	3. Naked Seed Class															
18	2	1.18	8.45	15.0	7	0.71	9.33	6.9	—	—	—	—	9	0.82	9.13	8.7
19	49	0.58	8.45	6.5	152	0.51	8.89	5.4	73	0.44	8.70	4.8	274	0.50	8.76	5.4
All	51	0.60	8.45	6.8	159	0.52	8.91	5.5	73	0.44	8.70	4.8	283	0.51	8.77	5.5
	4. Three Seed Classes Combined															
All F_2	229	2.95	8.60	24.3	646	2.87	8.81	23.3	302	2.87	8.83	23.1	1,177	2.89	8.78	23.4

test resulted in a probability value slightly beyond 0.80. These seed cover and plant color results confirm the previous work of Carver (1) and his conclusion that seed cover or naked seeds and red plant color are inherited independently.

SEED COVER AND LINT

Lint index and lint percentage in this work are rather closely associated. Either or both terms may be used to express level of lint production or lint level of the plants or groups of plants involved. The lint level in the two Winesap parental strains corresponded closely, but with the value of the one used in cross I slightly higher than that of the one used in cross II. On the other hand, the lint level of the No Lint parental strain of cross II was somewhat higher than that of the one of cross I.

The lint level of the F_1 is much lower in cross I than in cross II. This difference can hardly be accounted for as resulting from the small difference between the two Winesap parental plants or the small difference between the two No Lint parental plants. However, this F_1 difference appears real as it is confirmed by the generally lower levels of lint index and lint percentage found in the F_2 of cross I. The average lint index of the 1,502 F_2 plants of cross I is 2.49, while that of the 1,177 F_2 plants of cross II is 2.89. The average lint percentage of the former group is 20.1, while that of the latter is 23.4.

For study of the relationship of seed cover and lint level in the F_2, the lint index and lint percentage means have been summarized irrespective of plant color in the right-hand section of Tables 2 and 3. In these summaries the contrasted lint levels between the fuzzy and naked classes, in either cross, have approximately the same spread as that occurring between parental strains, but with the exception of lint percentage of the fuzzy class in cross II, they have dropped somewhat from corresponding positions of the fuzzy and naked parents. Smaller or lighter seeds in this case accounted for lack of the usual downward trend. The summaries of the F_2 naked-adherent class show lower lint index means than their respective F_1 groups. Lint percentage of this F_2 class is also lower than in the F_1 in cross I, but not in cross II. Lighter seeds in the latter case also appear to provide the offsetting effect here as in the fuzzy class of this cross. The three F_2 class lint levels for both variables and in either cross, although generally lower, tend to resemble relatively those in the Winesap parental strain, the F_1, and the No Lint parental strain.

The significance or lack of significance of lint index difference and of lint percentage difference among or between the F_2 seed cover classes and between the seed grades within these classes is indicated by F values reported in Table 4.[10] For both the lint index and the lint percentage mean differences among the fuzzy (nn), the naked-adherent (Nn), and the naked (NN) classes in cross I and in cross II very large F values, as expected, are shown. In both crosses and for both variables the three possible paired comparisons among the three seed cover classes also rendered high F values, but their mag-

[10]The 5th, 8th, 12th, and 14th lines or horizontal sections include the F values reported for the seed cover and lint level relationships.

TABLE 4.—*F values of lint index, seed index, and lint percentage mean differences among plant color classes, among seed cover classes, and between the various seed cover grades of the naked-adherent and naked groups, crosses I and II, No Lint × Winesap.*[1]

Horizontal section	Seed cover	Plant color (class symbols[4])	F value, cross I				F value, cross II			
			Number of plants	Lint index	Seed index	Lint percentage	Number of plants	Lint index	Seed index	Lint percentage
					Naked-Adherent					
1	15[2]	RR, Rr & rr	107	—[6]	—[6]	—[6]	132	4.88†	5.30†	—[6]
	16	RR, Rr & rr	584	1.13	—	—	430	—[6]	—[6]	1.18
	17	RR, Rr & rr	69	—	—	—	29	—	1.10	—
	All	RR, Rr & rr	760	—	—	—	591	—	2.70	—
2	15 & 16	RR	149	—	6.96†	4.99*	111	3.18	14.40†	2.47
	15 & 17	RR	47	7.79†	5.86*	14.12†	26	1.35	12.11†	9.22†
	16 & 17	RR	146	7.59†	—	9.76†	95	5.00*	—	9.63†
3	15 & 16	Rr	361	9.99†	2.13	16.04†	304	4.52*	—	10.31†
	15 & 17	Rr	85	12.69†	3.39	31.36†	84	11.77†	5.34*	27.31†
	16 & 17	Rr	340	3.20	2.95	6.67*	254	7.17†	4.23*	21.97†
4	15 & 16	rr	180	2.10	3.08	6.70*	145	1.91	9.14†	14.53†
	15 & 17	rr	43	3.44	15.89†	13.80†	49	3.02	17.94†	21.88†
	16 & 17	rr	167	—	3.68	4.39*	110	1.32	10.17†	9.67†
5	15 & 16	Combined[5]	690	11.00†	9.98†	27.64†	560	2.81	12.97†	24.46†
	15 & 17	Combined[5]	175	25.55†	14.62†	64.80†	159	15.96†	24.53†	58.43†
	16 & 17	Combined[5]	653	10.70†	6.99†	21.09†	459	12.51†	11.07†	41.12†

Naked

6	18	RR, Rr & rr	10	122	—	1.30	—	—	—	—
	19	RR, Rr & rr	365	2.93	—	2.65	274	3.89*	2.53	4.74†
	All	RR, Rr & rr	375	3.10*	—	2.85	283	4.82†	2.84	6.03†
7	18 & 19	RR	85	1.65	—	1.45	51	6.79*	—	9.54†
	18 & 19	Rr	204	—	—	—	159	3.13	—	1.66
	18 & 19	rr	86	1.17	1.28	1.58	—	—	—	—
8	18 & 19	Combined[5]	375	2.36	—	2.43	283	9.88†	—	9.22†
9	nn & Nn[3]	RR	244	553.07†	1.09	440.07†	178	352.95†	—	375.63†
	nn & NN	RR	158	3,965.69†	2.20	7,498.44†	113	1,910.51†	—	2,205.92†
	Nn & NN	RR	256	1,435.32†	—	1,920.82†	167	1,069.38†	—	1,110.69†
10	nn & Nn	Rr	590	1,866.30†	2.01	1,517.01†	487	698.95†	—	731.94†
	nn & NN	Rr	400	12,233.25†	2.47	20,876.25†	323	6,022.40†	1.37	9,610.50†
	Nn & NN	Rr	598	4,394.09†	—	5,847.03†	482	2,958.48†	1.09	4,201.11†
11	nn & Nn	rr	293	1,024.65†	5.49*	782.56†	229	451.20†	—	421.03†
	nn & NN	rr	184	5,734.70†	7.32†	8,973.48†	150	4,110.51†	1.07	5,932.40†
	Nn & NN	rr	281	2,311.09†	1.13	3,212.95†	225	1,914.48†	1.10	2,430.70†
12	nn & Nn	Combined[5]	1,127	3,387.83†	7.04†	2,696.67†	894	1,475.74†	—	1,510.80†
	nn & NN	Combined[5]	742	21,914.46†	10.06†	37,318.33†	586	11,717.38†	—	16,593.61†
	Nn & NN	Combined[5]	1,135	8,024.43†	1.18	10,795.84†	874	5,834.97†	—	7,566.32†
13	Total	RR, Rr & rr	1,502	1.05	—	—	1,177	—	3.22*	—
14	Total	nn, Nn & NN	1,502	8,389.80†	5.70†	10,672.07†	1,177	5,080.19†	—	7,150.76†

*Significant.
†Highly significant.
[1]Since few significant mean differences are evident within the fuzzy seed group, the F values for this group are not tabulated. Those that do demonstrate significance, however, are discussed in the text.
[2]Grades expressed numerically.
[3]NN = Naked; Nn = Naked-Adherent; nn = fuzzy.
[4]RR = Red; Rr = Intermediate Red; rr = Green.
[5]Total of three plant color classes.
[6]Where dashes are used, the mean square for "Between Classes" is numerically less than "Within Classes."

nitudes were governed by the degree of separation of the means concerned. The highest of such values are shown to occur between the fuzzy (nn) and the naked (NN) classes; next highest between the naked-adherent (Nn) and naked (NN) classes; and of a third order or lowest between the fuzzy (nn) and the naked-adherent (Nn) classes.

The relation of lint level among the seed grades within the fuzzy classes of both cross I and cross II confirms results of similar studies already reported by Jenkins, Hall, and Ware (5) and by Ware (16). In Tables 2 and 3, the means for both lint index and lint percentage do not materially rise or fall throughout the series of grades of the fuzzy class (grades 4 to 10 inclusive). The F values computed for all possible paired comparisons between these grades for both variables in both crosses indicated no significant differences in lint level among these grades.

Significant differences in F_2 lint level among the higher grades of the naked-adherent class and between the two grades of the naked class usually occur. Jenkins, Hall, and Ware (5) did not obtain a noticeable drop in lint level from grade 14, through grade 15 and grade 16, but a decided drop from grade 16 to grade 17.[11] Ware (16) found no significant change in lint index[12] between grades 14 and 15, but a drop from the latter to grade 16. In the F_3 of his material no significant changes occurred between grades 13[13] and 14 or between 15 and 16, but a drop between grades 14 and 15 was evident.

In the right-hand section of Table 2, the mean levels of lint index for grades 15, 16, and 17 of cross I are shown to be 2.78, 2.61, and 2.41, respectively, and the corresponding lint percentages 24.1, 22.4, and 20.4. In the results of cross II, similarly shown in Table 3, the lint index means are 3.21 for grade 15, 3.14 for grade 16, and 2.77 for grade 17, and the corresponding lint percentage means are 27.6, 26.2, and 22.2. In Table 4, the respective mean differences among these grades are shown to be highly significant except for lint index between grades 15 and 16 of cross II where the drop from the former grade to the latter is insufficient to show a real difference. The F values are largest between grades 15 and 17 for both variables in both crosses which is to be expected.

Differences in mean lint index and mean lint percentage between grades 18 and 19 were shown by Jenkins, Hall, and Ware (5) to be pronounced. Ware (16) also showed a similar difference for lint index. In the right hand section of Table 2, grade 18 of cross I has lower means for lint index and lint percentage than grade 19 of this group. The means of the former grade are 0.21 for lint index and 2.3 for lint percentage, and of the latter grade 0.29 for lint index and 3.1 for lint percentage.[14] The regular order follows in cross II (Table 3), the lint index and lint percentage for grade 18 being 0.82 and 8.7 and for grade 19, 0.50 and 5.4.

[11]Grade 17, as noted previously, is a transitional grade between naked-adherent and naked, but this grade was placed more or less arbitrarily in the former class.

[12]Lint percentage results were not given in that report.

[13]Grade 13 occurred in the F_3 but not in the F_2 group of that work.

[14]This reversal is probably attributable to the very small number of plants occurring in grade 18 for both crosses. Possibly inadequate samples were represented.

PLANT COLOR AND LINT

In cross I, the F_2 means of both lint index and lint percentage rise slightly from the red class to the intermediate red class and to the green class, while in cross II these F_2 mean levels of the two variables are in reverse order except in the green and intermediate red classes where the lint index is the same in both cases. These differences among the plant color classes in both crosses, however, are of insufficient size to be significant, as indicated by the F test (Table 4).

The lint level of the individual F_2 seed grades as compared among the three plant color classes in general also does not appear to be differentially affected by plant color except in a few individual cases which may be attributable to other causes. The respective lint index and lint percentage means of the fuzzy grades (4 to 10, inclusive) in cross I, when compared by individual grade across the plant color classes, showed no significant F values for either variable. This was likewise true for both variables of these grades in cross II except in the case of grade 10 where an F value corresponding to a point between 0.01 and 0.05 occurred for lint percentage.

The lint index and the lint percentage mean differences in the seed cover grades (15, 16, and 17) of the naked-adherent class and in the seed cover grades (18 and 19) of the naked class, when compared among the three plant color classes for both crosses, indicated no differential effects of plant color on lint except in two grades of cross II. These differences occurred in lint index in grade 15 and in both lint index and lint percentage in grade 19. In Table 3 it is shown that the mean value for lint index of grade 15 in the red class is lower than its expected level. This deviation doubtless accounts for the sizes of the F value for this comparison shown in Table 4. Both the lint index and lint percentage means in grade 19 progressively decrease from the red class to the intermediate red class and to the green class. This intergrade difference is significant for lint index and highly significant for lint percentage as shown in Table 4.

SEED COVER AND SEED INDEX

Seed index levels between parental strains of both cross I and cross II were not widely separated as was the case with the lint levels, and in the recovered parental seed cover types of the F_2 the seed index differed less than in the parental material. The seed index means of the parental strains in cross I differed by 1.25 grams, while the seed index means of the two recovered parental types differed by only 0.24 gram. The seed index means of the parental strains of cross II differed only by 0.23 gram and the seed index means of the F_2 parental types were identical. In the reports by Ware (15) and by Jenkins, Hall, and Ware (5) where the difference in the mean seed index between parents was large (approximately 4 to 5 grams), the seed index values were practically leveled out among the three classes in the F_2. Possibly no more weight than that added by the attached fuzz occurred in the seeds of the fuzzy class of those studies.

In cross II the seed index mean of the F_2 naked-adherent class was also practically identical with both F_2 parental types, while in cross I

it varied among the three seed cover classes. The F_2 seed index mean of cross I is 9.23 for fuzzy, 9.05 for naked-adherent, and 8.90 for naked. Most of the extra weight in the fuzzy class in this cross is attributable possibly to the weight of the fuzz itself, but it did not follow that the attached fuzz in the fuzzy F_2 class of cross II increased its seed weight. The F tests for cross I indicate significant difference in seed weight between the fuzzy (nn) and the naked-adherent (Nn) classes and between the fuzzy (nn) and the naked (NN) classes. The F value for the latter difference is larger than for the former difference, but when the naked-adherent and the naked classes are paired and tested, the difference is not significant. The seeds having fuzz attached according to these tests are heavier than those of the two fuzzless classes.

The seed index means of the seed cover grades did not vary significantly within the fuzzy class or within the naked class of cross I (Table 4). Such differences were not expected nor did they appear in cross II. On the other hand, significant differences between the seed index means of the seed grades occurred in many cases in the naked-adherent class of both crosses (Table 4). Inspection of seed index data of the naked-adherent class in Tables 2 and 3 does not reveal any consistent mean differences as related to the seed grades. The variations responsible for the real differences exhibited by the F test in these groups doubtless were of a nongenetic or fluctuating character. The seed index means of the seed cover grades in Jenkins, Hall, and Ware's (5) work, showed no consistent difference of seed weight among their F_2 naked-adherent subclasses or grades. Since the differences between seed grades of the naked-adherent class were about as large in cross II as in cross I, it would appear that these variations are not of a genetic nature but attributable to differential environment or other influences.

PLANT COLOR AND SEED INDEX

Plant color and seed index in the F_2 generation of either cross I or Cross II did not appear to be definitely associated. The seeds of the green plants in both crosses were slightly heavier than those of the other two plant color classes, but among these three classes the F test (Table 4) shows the seed index mean differences in cross II to be barely significant and in cross I to be nonsignificant.

Comparisons of the seed index means of each of the seven F_2 fuzzy seed grades respectively across the three plant color classes in both crosses indicated no significant differences as would be influenced by plant color. Likewise, in the same sort of comparisons of each of grades 15, 16, 17, 18, and 19, across the plant color classes, no significance is shown for seed index except in grade 15 of cross II. The unusual drop of the seed index mean in the red plant color class shown in Table 3 accounts for this exception.

SUMMARY

Seed cover and red plant color are inherited independently, while naked seeds and sparse lint are either controlled by two completely

linked genes or by the same gene. The F_2 generation segregated into three general seed cover classes, *viz.*, fuzzy, naked-adherent, and naked. The highest lint level of the three classes is associated with the first class; high lint, but at a definitely lowered level than in the first class, is associated with the second class; and very low lint level, or the sparse degree, is associated with the third class. Seed cover grades (4 to 10, inclusive) do not change in lint level within the fuzzy class, while in the naked-adherent seed grades (15, 16, and 17) and in the naked seed grades (18 and 19) there is a drop in lint level in most cases from the lower to the higher grades. The amount of lint becomes lower as the broken-off lint base attachments decrease. The relative abundance of these attachments seems to be associated with lint population and to be responsible after ginning for the particular seed-coat appearance.

The progenies of the two Winesap plants belonged to different populations as to seed cover but had very little differential effect on the seed grades of the respective hybrid progenies of the crosses they entered. When plants with thin seed cover represented by either of the Winesap plants are crossed with naked seeded plants, the F_2 generation produces among the seed grades within its fuzzy seed class a bimodal curve. This condition is in contrast with fuzzy class monomodal distribution which occurs when plants having heavy seed cover enter crosses with naked seeded plants.

Plant color is independent of lint level. Seed index does not appear to be associated with seed cover except for the extra weight contributed by the attached fuzz. Higher seed index possibly may be associated with green plant color, but the F value found for this variable in the three plant color classes fails to establish definitely this relation as a fact.

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MEASUREMENTS OF RECOVERY AFTER CUTTING AND FALL DORMANCY OF VARIETIES AND STRAINS OF ALFALFA, *MEDICAGO SATIVA*[1]

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THIS paper presents the results of studies on technics for the numerical expression of varietal differences in the vegetative responses of alfalfa in Wisconsin after the first cutting, and the degrees of dormancy during the fall period of growth. The term *recovery*, as used in this paper, refers to the rate and character of the new vegetative growth of alfalfa after the first cutting in the summer, while *dormancy* deals with the rate and character of growth after the second cutting and during the fall period. Both rate of recovery and degree of fall dormancy are inherent characteristics of the varieties of alfalfa studied, although their expressions are modified by environmental conditions. Field observations of certain varieties and strains which express major differences in fall dormancy and the rate of recovery after cutting are recorded in the literature. The data presented in this paper add weight to their validity.

METHODS AND PROCEDURE

Growth responses were measured during two periods, since but two cuttings of alfalfa are obtained normally under Wisconsin conditions. The rate of recovery was measured three times at irregular intervals after the first crop had been removed on July 3, 1937. Measures of fall dormancy were made twice during the fall period of 1937 (3 and 7 weeks after the second crop of hay was harvested on September 2, 1937) and once the following year after the second cutting was made on August 26, 1938.

The 196 plots of alfalfa (1/200 acre each) used in these trials were sown on July 25, 1935, on limed and heavily fertilized Miami silt loam soil on a fairly level area of the University Farm at Madison, Wis. Seed of the eight varieties of alfalfa sown included a total of 49 strains which were of the following origins: 29 strains of Ladak grown in Montana, Oregon, South Dakota, and Wyoming; 8 strains of Cossack grown in Idaho, Montana, and Wyoming; 4 strains of Grimm grown in Wisconsin; 4 strains of Common grown in South Dakota, Wyoming, Wisconsin, and Ohio; 1 strain of Hardistan grown in Nebraska; 1 strain of Turkistan imported commercially; 1 strain of Norwis grown in Wisconsin; and 1 strain of Hardigan grown in Michigan. Each lot of seed from a given source is regarded as a regional strain of the aforementioned varieties.

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The 49 strains were sown by hand in randomized blocks with 4 replications and at the rate of 30 pounds per acre. Extreme care was taken to prevent any mixing of the seed from plot to plot. An 8-foot border of Ohio Common extended adjacently along one end of each plat, and likewise Montana Cossack extended adjacently at the other end. In the fall of 1935 there was a thick, uniform stand on each plot and this condition prevailed until 1937 when a few spots of relatively low elevation showed severe winter injury from ice sheets. These areas were easily recognizable and were avoided in making the readings on recovery and dormancy. With this exception, uniformity prevailed until the summer of 1938 at which time symptoms of bacterial wilt disease (*Phytomonas insidiosa*) made their first appearance and the plots of susceptible strains were thinned by its effects. Insect damage was of minor importance in these trials.

All plots were cut twice in 1936, late in June and late in August. The first cutting in 1937 was taken on July 3. This growth was very heavy due to abundant moisture in the spring of 1937. The second crop was harvested September 2 and proved to be much less productive than the first cutting due, in part, to dry and hot weather.

DETERMINATION OF SUMMER RECOVERY AFTER CUTTING

The first crop of hay was cut at a level of about 2 inches above the soil surface on July 3, 1937, at which time the alfalfa was in full bloom and abundant storage of foods had occurred in the roots. Eleven days later (July 14) all plots showed definite signs of producing new growth, but it was clearly evident that some varieties were recovering much more rapidly than others. In order to measure such differences the area of ground covered by the young top growth was estimated with the aid of a grid quadrat. This frame had an enclosed area of 100 square inches and was subdivided by wires into 25 2-by-2 inch squares. By throwing the grid at random about the plot, a rapid and fairly accurate estimate of the percentage of ground cover could be ascertained by giving each sub-square where the soil coverage was complete a value of 4, and each partially covered sub-square a value of 0, 1, 2, or 3 as the case deserved. The total of these figures gave the percentage of ground covered by green top growth beneath the grid. When the alfalfa was short, the grid was placed directly on the ground. Later, the frame was raised on "stilts" so as not to disturb the taller and erect alfalfa while taking the reading. These "stilts" consisted of four metal legs which slid through holes in the corners of the frame and were held in place with thumb screws. Four random determinations were made on each replicate for all strains on July 14, and 22 and August 17, 1937. The average height of the alfalfa in inches was determined in each frame at the same time the coverage readings were taken.

Ground coverage of alfalfa is dependent upon many factors, such as the numbers of plants per unit area, the numbers of buds per plant and their activity in terms of internodal elongation and leaf developments, the size and shape of the crown, the position of the stems in relation to decumbency and erectness, the number and size of leaflets, and, in fact, all visible characters of growth. By evaluating the ground coverage, a numerical expression is obtained of the effect of all these characters rather than any one of them. Supplementing the determinations of ground coverage with measurements of the height gave additional evidence with respect to the position of the stems in relation to summer recovery.

RESULTS

LADAK SLOW TO RECOVER

The marked differences in recovery, easily discernible in the field, appear equally outstanding in the data. The data collected on the percentages of ground coverage of the alfalfas on July 14 and 22 and on August 17, 1937, are recorded in Table 1 as the means of all strains for each of the eight varieties. In addition, calculated percentages of recovery are also tabulated. The latter are based on the ground coverages, applying the value of 100% recovery to Grimm alfalfa which stood highest in its average ground coverage, 11 and 19 days after cutting, and was superseded only by one strain (Norwis) 44 days after cutting.

With respect to immediate recovery, i.e., 11 days after cutting, the average ground coverage (Table 1) was highest (15.31%) for the Grimm variety and lowest (6.10%) for Ladak. On the basis of the calculated percentage of recovery, the eight varieties arranged themselves in descending order as follows: Grimm, 100%; Common, 92.5%; Hardistan, 91.5%; Norwis, 84.1%; Hardigan, 75.1%; Turkistan, 74.7%; Cossack, 71.5%; while Ladak showed only 39.8% of the recovery expressed by Grimm. Grimm, Common, and Hardistan had well started the production of the second crop, while Ladak had only begun recovery in the intervening 11 days.

The individual strains of the four varieties which were represented by more than one strain did not all perform alike but showed significant variability in some cases, as shown by the relative range in the percentage of ground coverage, as follows:

Grimm,	4 strains—	13.06 to 18.31%
Common,	4 strains—	13.38 to 16.00%
Cossack,	8 strains—	8.62 to 13.00%
Ladak,	29 strains—	4.44 to 9.37%

Except for one strain of Cossack which ranked slightly below (difference not statistically significant) the two highest strains of Ladak, all of the 29 strains of Ladak gave the lowest percentages of recovery. The differences between some of the strains within each variety are significant at this stage of recovery and this is particularly true in case of the Ladak.

After 19 days of growth, the ground coverage had increased with all varieties. Grimm and Ladak still held the extreme positions (Table 1), while the other varieties ranged between them, with only a moderate change in their ranking order from that of the week before. A narrowing of the range of the percentages of recovery (49.9 to 100%) is evident on July 22 when compared with that on July 14 (39.8 to 100%). This indicates that Ladak, the slowest to start recovery, is making a more rapid growth than the other varieties now that recovery is well under way. The range in variability within the 4 strains of Grimm was 24.38 to 30.00%; 4 strains of Common, 22.56 to 32.50%; 8 strains of Cossack, 18.56 to 23.81%; and 29 strains of Ladak, 11.87 to 17.63.

TABLE 1.—*Average percentages of ground coverage and calculated percentages of recovery of the second growth of eight varieties of alfalfa taken 11, 19, and 44 days after the first cutting on July 3, 1937.*

Variety	No. of strains	Ground coverage and % recovery after cutting on July 3, 1937								
		After 11 days			After 19 days			After 44 days		
		Rank	Average coverage, per cent*	Recovery, per cent	Rank	Average coverage, per cent†	Recovery, per cent	Rank	Average coverage, per cent‡	Recovery, per cent
Grimm	4	1	15.31	100.00	1	27.65	100.00	2	62.90	100.00
Common	4	2	14.16	92.48	3	26.67	96.45	4	59.39	94.42
Hardistan	1	3	14.00	91.45	5	21.00	75.95	8	49.56	78.79
Norwis	1	4	12.87	84.06	2	26.75	96.74	1	65.75	104.53
Hardigan	1	5	11.50	75.11	7	20.25	73.24	6	54.06	85.95
Turkistan	1	6	11.44	74.72	4	24.06	87.02	7	50.75	80.68
Cossack	8	7	10.95	71.52	6	20.84	75.37	3	61.52	97.81
Ladak	29	8	6.10	39.84	8	13.80	49.91	5	54.07	85.96

The minimum difference necessary to be significant at the 5% level between strain means at any one date was found to be as follows:

*1.54.
†5.57.
‡10.18.

With 44 days of growth, the ground coverage (Table 1) of all varieties increased greatly over the values expressed earlier in the recovery period. At this early bloom stage of growth, Grimm possessed a ground coverage of 62.9% and was on a par with Norwis (65.8%). The Turkistan and Hardistan varieties showed the least recovery (50.8 and 49.6% ground coverage, respectively), while Cossack (61.5%) and Ladak (54.1%) have advanced to third and fifth rank, respectively.

Although a comparison of the variability of 29 strains of one variety with only 4 strains of another is not to be justified, it is worthy of mention that the Ladak strains not only showed a much greater relative range of variability in ground coverage with 11- and 19-day periods of recovery but also with 44 days as follows:

Grimm,	4 strains—60.12 to 65.68%
Common,	4 strains—55.31 to 62.12%
Cossack,	8 strains—58.31 to 63.06%
Ladak,	29 strains—47.25 to 62.60%

The uniformity in the performance of Grimm alfalfa has been recognized in previous trials as has the variability of Ladak, and such contrasts in this trial are set forth as matters of interest. The variability occurring between strains of all varieties did not appear to be associated with the region or state where the seed was produced.

The minimum significant difference between strain means as calculated by the analysis of variance proved to be small (1.54) early in the recovery period and many strains were significantly different within 11 days after cutting. However, at the bloom stage (44 days of recovery) the minimum significant difference between strain means was much larger (10.18) and fewer of the existing variations were significant. F-values for between strains, from data taken on July 14 (60.22), July 22 (6.67), and August 17 (1.73), were far above the 1% level of significance (1.67).

In summary, measurable and significant differences were found in recovery 11 and 19 days after the first cutting of the eight varieties of alfalfa under trial; and such differences were very pronounced in a comparison of Grimm and Common with Cossack and Ladak. Many of these differences narrowed to a point of insignificance after 44 days of growth, the slower Ladak and Cossack varieties having "caught up" with the more rapidly recovering Grimms and Commons. In the late bloom stage (September 1) the ground coverage was observed to be nearly complete in all plots. The data seem to bear out the belief that with the use of a grid quadrat, varietal and strain variability in ground coverage can be expressed numerically with a reasonable degree of accuracy.

HEIGHT AN INDEX OF RECOVERY

Measurements of the height of the alfalfas taken on 11, 19, and 44 days after cutting are recorded in Table 2 for each of the eight varieties. The trends of these data follow closely those pertaining to ground coverage and this similarity is indicated by significant corre-

lation coefficients of .872 on July 14, .915 on July 22, and .582 on August 17. Although the correlations were higher 11 and 19 days after cutting, all of them far exceeded the 1% level of significance (.360). The rankings of the varieties are very similar for measurements of ground coverage and height (Tables 1 and 2) with the one exception of the Ladak variety 44 days after cutting. Apparently, with the varieties used in these trials, the height of growth also proved to be a good index of recovery.

METHODS OF DETERMINING FALL DORMANCY

Fall dormancy refers to a decumbent type of vegetative growth of alfalfa occurring during the autumnal period at which time internodal elongation is greatly retarded. In these trials, plants with but little dormancy stood erect with many long stems, whereas the more dormant types were shorter and were characterized by leafiness and a spreading habit of growth. To measure such responses, a dormancy value was given to the individual plants of each plot with the aid of a frame having an enclosed area 1/20,000 acre. This frame, thrown at random four times on each of the four replicate plots, supplied 16 readings for each of the 49 strains represented. The plants included in the frame were numerically evaluated. The tallest and most erect were given a value of 5, the shortest and most decumbent a value of 1. Intermediate plants were accorded values of 2, 3, or 4 as their condition warranted. Within each frame each plant of the No. 1 class was given a value of 1; each No. 2 plant a value of 2; each No. 3 plant a value of 3, etc. The sum of these values divided by the total frequency within the frame gave an index, inversely proportional to the dormancy of the plants within that particular frame. For example, if in one reading two No. 1 plants, three No. 2 plants, three No. 3 plants, one No. 4 plant, and no No. 5 plants were observed, the dormancy value of the plants within that frame would be determined as $\frac{2 + 6 + 9 + 4 + 0}{9}$ or 2.3. Readings on the whole series (the same plats being used as were used in making determinations on relative rate of recovery during the summer) were taken at two dates during the fall period, *viz.*, September 25 and October, 23, 3 and 7 weeks, respectively, after cutting on September 2, 1937.

VARIATIONS IN FALL GROWTH RESPONSES

The autumnal responses of the varieties and strains after cutting on September 2, 1937, showed marked similarity to the rates of recovery during the previous summer. Strains of alfalfa slow to recover after the first cutting were, with few exceptions, the ones to show a marked early fall dormancy. The data on fall dormancy are condensed in Table 3 by obtaining the means for all strains of eight varieties of alfalfa under trial. In addition, each variety is ranked in relation to the other varieties according to the degree of dormancy it expressed. The Common, Grimm, and Hardigan varieties gave the highest values expressing the least degree of fall dormancy, while Hardistan, Turkistan, and Ladak held the other extreme showing the

TABLE 2.—*Average height and calculated percentages of recovery based on height of the second growth of eight varieties of alfalfa 11, 19, and 44 days after cutting on July 3, 1937.*

Variety	No. of strains	Height in inches and % recovery after cutting July 3, 1937								
		After 11 days			After 19 days			After 44 days		
		Rank	Height, in.	Recovery, per cent	Rank	Height, in.	Recovery, per cent	Rank	Height, in.	Recovery, per cent
Grimm	4	2	2.34	100.00	1	8.11	100.00	2	10.69	100.00
Common	4	1	2.49	106.41	2	7.57	93.34	3	10.61	99.25
Hardistan	1	3	2.10	89.74	5	6.96	85.69	7	9.75	91.21
Norwis	1	4	2.10	89.74	3	7.56	93.09	1	10.75	100.56
Hardigan	1	5	2.09	89.31	6	6.94	85.57	5	9.87	92.33
Turkistan	1	6	2.09	89.31	4	7.44	91.73	6	9.81	91.77
Cossack	8	7	1.92	82.05	7	6.94	85.58	4	9.99	93.45
Ladak	29	8	1.50	64.10	8	4.78	58.69	8	8.71	81.48

greatest degree of dormancy throughout the fall. Cossack and Norwis were intermediate.

TABLE 3.—*Average fall dormancy values expressed by eight varieties of alfalfa, 3 and 7 weeks after cutting on September 2, 1937, with the varieties are arranged in descending order of their values of mean fall dormancy.*

Variety	Value of dormancy after cutting September 2, 1937					
	Sept. 25		Oct. 23		Mean	
	Rank	Value*	Rank	Value*	Rank	Value†
Common	1	3.63	1	3.97	1	3.80
Grimm	2	3.57	3	3.68	2	3.63
Hardigan	4	3.25	2	3.88	3	3.58
Norwis	3	3.38	5	3.20	4	3.30
Cossack	5	3.12	4	3.39	5	3.26
Hardistan	6	2.70	7	2.65	6	2.68
Turkistan	7	2.60	6	2.70	7	2.65
Ladak	8	2.05	8	2.31	8	2.19

The minimum difference required to be significant at the 5% level between strain means at any one date was found to be as follows:
*0.46.
†0.33.

Although all strains of Ladak expressed greater dormancy than those of Grimm, Common, and Cossack, a much wider relative range of variability occurred in the 29 strains of Ladak, as is indicated by the following data:

Common,	4 strains—3.55 to 3.90
Grimm,	4 strains—3.33 to 3.90
Cossack,	8 strains—2.95 to 3.50
Ladak,	29 strains—1.90 to 2.70

The strains of Ladak were also highly variable in recovery after the first cutting, but such variability in both summer recovery and fall dormancy could in no way be associated with any particular region or state from which the seed was obtained.

Statistical analysis of the data on dormancy shows a minimum significant difference at the 5% level, as calculated by the analysis of variance, of 0.46 between any 2 of the 49 strains at either date during the fall, and for the mean fall dormancy a minimum significant difference of 0.33. Actual differences far exceeded these figures in a large number of cases. Data collected at the two dates during the fall compare very closely. A minimum significant difference of 0.40 between the two readings (3 and 7 weeks after cutting on September 2) for any single strain exceeds actual differences in the majority of cases. F-values for strains (37.44) and dates (67.34) both exceeded the 1% level of significance (1.75 and 6.01, respectively), while the F-value for the interaction of strains × dates (1.19) did not show significance even at the 5% level (1.44).

EMPIRICAL ESTIMATES OF DORMANCY

Empirical ratings were made independently by two observers of the dormancy of these same alfalfas the following fall, on October 28, 1938. This was accomplished by observing the individual plots without knowledge of their identity and assigning them a position of relative dormancy from 1 to 5. These estimated ratings differ from the numerical determinations of the previous fall in that the individual plot was graded as a whole from the general appearance of all the plants, while the indices of dormancy afforded the previous fall were of random samplings within the plot. The ratings of 1938 were by far the more general, but because of the generality they are also of value.

The data for these estimates are included in Table 4 where the numbers of plots of a given rating are recorded in the corresponding column. In addition, a hypothetical dormancy value is calculated by giving each individual plot rated at 5, a value of 5; each plot rated at 4, a value of 4; etc. The sum of these values divided by the total number of plots representing the variety gives the numerical index of dormancy expressed in the extreme right hand column.

TABLE 4.—*Estimates of fall dormancy in terms of the number of plots of a variety of alfalfa giving a relative dormancy rating of from 1 (extreme dormancy) to 5 (very little or no evidence of dormancy) as each plot appeared to two observers making independent estimates on October 28, 1938.*

Variety	Rank	Number of plots with dormancy rating of					Calculated dormancy values
		5	4	3	2	1	
Common .	1	10	4	2	—	—	4.5
Grimm. . .	3	—	8	8	—	—	3.5
Hardigan.	2	—	4	—	—	—	4.0
Norwis. . .	4	—	1	3	—	—	3.25
Cossack. .	5	—	3	29	—	—	3.1
Hardistan	6	—	—	—	4	—	2.0
Turkistan	7	—	—	—	3	1	1.75
Ladak. . . .	8	—	—	2	70	44	1.64

It is of interest that these general ratings arrange the varieties in the same order of dormancy as did the determinations made the previous fall, with one minor exception. The four strains of the Grimm variety (3.5) were found to be slightly more dormant than the single strain of Hardigan (4.0), according to the ratings in 1938; while according to the measurements in 1937, Grimm (3.63) was determined to be on a par with Hardigan (3.58) with respect to fall dormancy. All other varieties arranged themselves in the same order with respect to fall dormancy; the Commons and Grimms being least dormant and the Hardistan, Turkistan, and Ladaks possessing the greatest degree of fall dormancy. These data were not treated statistically.

DISCUSSION

The varieties and nearly all the strains which were slow to recover early in the summer exhibited the greatest degree of fall dormancy.

This is shown by the high correlation (.895 and .899, respectively) between immediate recovery (11 and 19 days) after cutting and mean fall dormancy. However, the correlation coefficient at 44 days after the first cutting was much lower (.581) since the strains which were slow in immediate recovery tended to grow more rapidly as they approached the blossoming stages of growth. This situation did not prevail with respect to fall dormancy. The high correlation (.949) between determinations of fall dormancy taken early and late in the fall denotes consistency in the expression of dormancy by the alfalfa varieties throughout the fall period. (Significance at the 1% level equals .360).

Both height and ground coverage determinations were found to be criteria of the rate of recovery. The correlation coefficients expressive of the relationship between height and the percentage of ground coverage are .872 and .915 for 11 and 19 days, respectively, after the first cutting. However, 44 days after cutting the correlation coefficient is .582.

Unfortunately, no empirical observations were made with which to supplement the more elaborate technics for determining the relative rates of recovery after the first cutting. Had such simple observational methods been employed, it is probable that the major differences, at least, would have been in accord with the data presented here.

The data on summer recovery and fall dormancy are too limited to ascertain the variability which might prevail over a period of years or in relation to time and frequency of cutting, but it is believed that the numerical methods described would be of merit in making such determinations.

SUMMARY

Methods were devised to evaluate numerically eight varieties of alfalfa with respect to their characteristics of growth during the summer and fall periods. The numerical evaluations included the rate of recovery following the first cutting and the degree of dormancy of the growth during the fall period following the second cutting. Such measurements were made on 49 strains of alfalfa, including 4 strains of Grimm, 4 strains of Common, 8 strains of Cossack, 29 strains of Ladak, and 1 strain each of Norwis, Turkistan, Hardistan, and Hardigan.

Measurable differences in recovery were much more pronounced within 19 days after the first cutting of the eight varieties under trial than prevailed 44 days after the first cutting. The immediate recovery of Grimm, Common, and Hardistan was rapid, while Ladak was by far the most retarded. Norwis, Hardigan, Turkistan, and Cossack were intermediate in the order named. Late in the summer the measured differences in recovery of the second growth were greatly diminished. The trends of the data relative to the height of the alfalfa during the summer were closely correlated with those of ground coverage.

Varieties slow to recover after the first cutting were, with few exceptions, those showing the greatest fall dormancy. Rankings on the

basis of increasing dormancy of varieties of alfalfa were as follows: Common, Grimm, Hardigan, Norwis, Cossack, Hardistan, Turkistan, and Ladak. The dormancy of a variety was expressed fairly consistently throughout the autumnal period. Variations in summer recovery and fall dormancy between strains within a variety were greatest in Ladak but such differences were not associated in any way with the region from which the seed was obtained.

Empirical evaluations of the relative dormancies of the 49 strains, supplemented the more elaborate measures of dormancy with comparable results. Undoubtedly the simpler observational estimates on whole plots would be adequate for the expression of the major differences in recovery and fall dormancy of such contrasting varieties as Grimm and Ladak, but more detailed numerical measures may be required for varieties where such differences are not as prominent.

CAUSES OF PREFERENCES EXHIBITED BY ANIMALS FOR CERTAIN INBRED LINES OF CORN[1]

E. ROBERTS AND IRWIN R. HOENER[2]

According to previous work by Roberts, Holbert, and Quisenberry,[3] rats showed distinct preferences for certain inbred lines of corn. The extremes of the lines tested were Wisconsin R3 and Illinois 90, R3 being preferred.[4] These two lines were chosen for further work, especially in respect to the cause of preference.

Circular cages were used and the positions of the feed dishes were changed daily. The corn was ground in a Hobart mill. Nearly all passed through a 20-mesh sieve and approximately 53% passed through a 35-mesh sieve. Daily feed consumption was recorded and dishes refilled. Animals were kept on test for 4 days, after which they were placed on the laboratory stock ration for 3 days or more before being used on another preference test.

The peference tests involving R3 and 90 grown in 1937 showed a marked preference for R3. The amount of R3 eaten was nearly four times that of 90 (Table 1).

TABLE 1.—*Preference tests of R3 and 90, 1937 crop.*

Number of rats in test	Average weight of rats, grams	Number of days on test	Total amount eaten, grams		Amount eaten in grams per 1,000 grams of body weight		R3/90
			R3	90	R3	90	
6	226.1	4	282	53	207.9	39.1	5.32
5	179.1	4	232	42	259.1	46.9	5.52
6	181.2	4	338	107	310.8	98.4	3.16
6	133.1	4	217	76	271.8	95.2	2.86
6	189.2	4	276	83	243.2	73.1	3.33
6	206.1	4	298	91	240.9	73.4	3.27
6	190.9	4	319	44	278.4	38.4	7.25
6	235.7	4	239	86	169.0	60.8	2.78
47	193.0		2,201	582	242.7	64.2	3.78

Because R3 and 90 differ distinctly in odor, it was thought that this difference might be responsible for the preference for R3 exhibited by the rats. That odor might be related to preference was suggested

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[3]ROBERTS, E., HOLBERT, J. R., and QUISENBERRY, J. H. Preferences for certain genetic strains of corn exhibited by animals. Jour. Amer. Soc. Agron., 30:150-159. 1938.

[4]The corn used in this study was obtained through the kindness of Dr. J. R. Holbert, formerly Senior Agronomist, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture.

by the changed behavior exhibited by rats which had accidentally been subjected to severe exposure to formaldehyde fumes during fumigation of the laboratory. Rats which had eaten 234 grams of R3 and 43 grams of 90 per 1,000 grams of body weight before fumigation, ate 156 grams of R3 and 101 grams of 90 after fumigation. This suggests that the sense of smell was affected by exposure to formaldedehyde, though it is possible that the sense of taste might also have been affected.

Other rats brought into the laboratory a few days after fumigation, but while the presence of formaldehyde was still very noticeable, ate 135 grams of R3 and 207 grams of 90 per 1,000 grams of body wei ht, showing a reversal of preference. Three months later progeny of rats which had been in the laboratory during fumigation were tested. They ate 294 grams of R3 and 96 grams of 90, showing the usual preference for R3.

Two experiments were designed to study the relation of odor to preference. In the first, extracts of the two inbred lines of corn were obtained by ether extraction of the ground corn. These extracts were then steam distilled. This last distillate from 90 was added to the extracted R3 meal and that of R3 to the 90 meal. After this addition, R3 smelled like 90 and 90 smelled like R3. Preference tests showed that the rats still preferred R3. The amount of R3 eaten per 1,000 grams of body weight was 212 grams and of 90 only 16 grams. This seems to exclude the odors which are extractable by the methods used as a causative agent for the difference in preference.

In the second experiment, evidence that the difference in odor between R3 and 90 was not the cause of preference expressed by the rats was obtained by the behavior exhibited before and after severing the olfactory nerves.[5] Before the operation 472 grams of R3 and 75 grams of 90 were eaten, while after the operation the anosmic rats ate 448 grams of R3 and 74 grams of 90 (Table 2). The evidence obtained from these two tests excludes the sense of smell as a factor in the preference shown for R3.

Neither does the cause of preference lie in the seed coats. Before removal of the seed coats 276 grams of R3 and 83 grams of 90 were eaten. After removal of the seed coats the rats ate 324 grams of R3 and 49 grams of 90 (Table 3).

When a preference test was made with a 1939 crop of R3 and 90 produced at Urbana, Ill., the difference in amounts eaten was rather small. Only 223 grams of R3 and 191 grams of 90 were eaten during the test. Per 1,000 grams of body weight the amounts were 185.3 and 158.7 grams for R3 and 90, respectively, while for the 1937 crop the amounts were 242.7 and 64.2 grams, respectively, for R3 and 90. Inspection showed that R3 of the 1939 crop was badly infected with Diplodia, while 90 was apparently free from infection. Diplodia-infected and Diplodia-free kernels were separated by visual examination, ground separately, and a preference test made. The rats ate 281 grams of the Diplodia-free corn and only 112 grams of the Diplodia-infected corn.

[5]The authors are indebted to Dr. L. A. Pennington of the Department of Psychology, University of Illinois, for performing these operations.

TABLE 2.—*Amounts of R3 and of 90 eaten by rats before and after the severance of the olfactory nerves.*

Number of rat	Weight, grams	Number of days on test	Condition	Total amount eaten, grams	
				R3	90
1349	306	4	Normal	77	19
	297	4	Anosmic	73	17
1350	262	4	Normal	71	16
	250	4	Anosmic	64	11
1351	280	4	Normal	73	19
	279	4	Anosmic	66	23
1385	264	4	Normal	86	9
	250	4	Anosmic	87	5
1390	229	4	Normal	80	7
	216	4	Anosmic	69	10
1391	258	4	Normal	85	5
	259	4	Anosmic	89	8
Totals			Normal	472	75
			Anosmic	448	74

TABLE 3.—*Choice of R3 and 90 before and after removal of seed coats.*

Number of rats	Average weight, grams	Days on test	Amounts eaten in grams of			
			With seed coats		Without seed coats	
			R3	90	R3	90
6	189	4	276	83	—	—
6	206	4	—	—	324	49

When preference tests were made of R3, 90, and R3×90(F_2),[6] the descending order in respect to preference was R3, R3×90(F_2), and 90, though the preference for R3 was significantly greater than for either R3×90 or 90 (Table 4). Later, we were fortunate in obtaining reciprocal crosses, R3×90 and 90×R3. The kernels involved were F_1 and not F_2, as shown in Table 4. When tested, the animals preferred R3×90 rather than 90×R3 (Table 5). They preferred the corn in which the endosperm was the result of two nuclei from R3 and one from 90. This suggests that the cause of preference lies in the endosperm.

Chemical analyses of R3, 90, and R3×90(F_2) of the 1937 crop were made and the results are given in Table 6. Association of preference with any of the chemical differences has not been established. The percentages of fat are in the same order as the preferences shown, but these differences as a cause of preference are eliminated because the preference is not changed by extracting the fat from R3 and 90.

[6]F_2 designates the second-generation seed produced on F_1 plants; and F_1 designates first-generation hybrid-seed produced on plants of the parental inbred lines.

TABLE 4.—*Preference tests of R3, 90, and R3 × 90(F_2), 1937 crop.*

Number of rats in test	Average weight of rats, grams	Number of days on test	Total amount eaten, grams			Amount eaten in grams per 1,000 grams of body weight		
			R3	90	R3×90	R3	90	R3×90
6	205.2	4	270	22	59	219.3	17.9	47.9
6	191.2	4	254	39	81	221.4	34.0	70.6
6	218.8	4	131	127	122	99.8	96.8	93.0
6	213.5	4	127	116	111	99.1	90.6	86.7
6	137.0	4	151	41	95	183.7	49.9	115.6
6	189.5	4	153	57	97	134.6	50.1	85.3
6	192.0	4	221	35	98	191.8	30.4	85.1
6	198.8	4	214	16	222	179.5	13.4	186.2
48	193.3		1,521	453	885	166.2	47.9	96.3

TABLE 5.—*Preference tests of R3×90(F_1) and 90×R3(F_1).**

Strain	Total amount eaten, grams	Amount eaten in grams per 1,000 grams of body weight
R3×90....................	418	342.6
90×R3....................	177	137.0

*Six rats were used, averaging 203.1 grams in body weight.

TABLE 6.—*Chemical analyses of R3, 90, and R3×90(F_2), 1937 crop.**

Strain	Ash	Protein	Fibre	Fat	N-free extract	Ca	Mg	P	K	Volatile oils†
90.........	1.87	13.31	2.68	4.87	77.27	0.250	0.131	0.426	0.496	0.34
R3........	1.43	11.67	2.08	6.30	78.52	0.131	0.109	0.314	0.417	0.97
R3×90(F_2)	1.43	12.11	2.37	5.51	78.58	0.110	0.138	0.311	0.376	0.87

*Reported as percentage on water-free basis.
†Calculated as difference in weight of ether extract dried over H_2SO_4 and when dried in oven at 100° C.

R3 appeared more yellow than 90. For this reason, and in the light of other work[7] which indicates a relation between color and provitamin A content, it was suspected that the difference in preference might be associated with provitamin A content. To test this possibility, β-carotene was added to 90. β-carotene and cottonseed oil were mixed in the proportion of 2 mg of carotene to 1 ml of cottonseed

[7]HAUGE, S. M., and TROST, J. F. An inheritance study of the distribution of vitamin A in maize. Jour. Biol. Chem., 80:107–114. 1928.
MANGELSDORF, P. C., and FRAPS, G. S. A direct quantitative relationship between vitamin A in corn and the number of genes for yellow pigmentation. Science, 73:241–242. 1931.

oil. This mixture and cottonseed oil alone were then mixed with the ground corn to give the following combinations:

1a, 625 grams 90 meal + 25 ml cottonseed oil + 50 mg β-carotene
1b, 625 grams 90 meal + 25 ml cottonseed oil
2a, 625 grams 90 meal + 12.5 ml cottonseed oil + 25 mg β-carotene
2b, 625 grams 90 meal + 12.5 ml cottonseed oil
3a, 625 grams 90 meal + 6.25 ml cottonseed oil + 12.5 mg β-carotene
3b, 625 grams 90 meal + 6.25 ml cottonseed oil

Results of preference tests indicated that the addition of β-carotene did not increase preference (Table 7).

TABLE 7.—*The effect on preference by rats of addition of carotene to 90.*

Mixture fed		Number of rats	Average weight of rats, grams	Amount eaten, grams	Amount eaten in grams per 1,000 grams of body weight
No.	Composition				
1a	90+3.7%* C. S. O.+0.008% β-carotene	18	156.9	574	203.2
1b	90+3.7% C. S. O.			766	271.2
2a	90+1.8% C. S. O.+0.004% β-carotene	6	155.3	164	176.0
2b	90+1.8% C. S. O.			173	185.6
3a	90+0.9% C. S. O.+0.002% β-carotene	6	164.4	223	226.1
3b	90+0.9% C. S. O.			215	217.9

*All percentages based on weight of corn.

Another question of interest is, without choice, how much of the different kinds of corn will be eaten? Table 8 gives the results of tests showing that without choice there is no significant difference in amounts eaten of R3, 90, and R3×90(F_2).

TABLE 8.—*Amounts of R3, 90, and R3×90(F_2) eaten without choice.*

Strain	Number of tests	Number of rats	Average weight of rats, grams	Total amount eaten, grams	Amount eaten in grams per 1,000 grams of body weight
R3.........	1	6	201.7	356	294
90.........	1	6	195.6	328	279
R3×90(F_2)	1	6	172.5	314	277

Another important question concerns possible differences in nutritive value of R3 and 90. A feeding test was made by J. H. Longwell[8] to determine if differences in growth resulted from diets differing only in R3 and 90. Each diet contained 20% casein, 4% salt mixture, 2% cod liver oil, and 74% ground corn. In one diet the corn was R3 and in the other 90. Eight pairs of rats were used. One member of the pair received the diet with R3 and the other received the

[8]Formerly Associate in Animal Husbandry, University of Illinois.

one with 90. Both ate the same amount during the test. The eight rats on the R3 diet gained 335 grams and those on the 90 diet gained 314 grams. The average difference in gain per rat was 2.6 grams in favor of those on the diet containing R3, but this difference is too small to warrant the conclusion that R3 is better than 90 for the purposes of growth.

SUMMARY

In an investigation of possible causes of the preference exhibited by rats for different lines of corn, two inbred lines were used, *viz.*, Wisconsin R3 and Illinois 90, and hybrids between them.

With choice of R3, 90, and $R3 \times 90(F_2)$, the greatest preference by rats was for R3, the least for 90, and for $R3 \times 90(F_2)$ the preference was intermediate.

The cause of preference is not associated with difference in odor of the corn or the sense of smell in the rat.

Infection of corn by Diplodia decreases the preference shown by the rats.

The seed coats were not involved in preference.

The addition of carotene to 90 did not increase preference.

The rats showed a greater preference for $R3 \times 90(F_1)$ than for $90 \times R3(F_1)$, suggesting that the cause of preference may be located in the endosperm.

Without choice, no significant differences in amounts eaten were found among R3, 90 and $R3 \times 90(F_2)$.

In paired feeding tests, the gains of rats on diets differing only in R3 and 90 did not differ significantly.

CALCIUM-BORON RATIO AS AN IMPORTANT FACTOR IN CONTROLLING THE BORON STARVATION OF PLANTS[1]

MACK DRAKE, DALE H. SIELING, AND GEORGE D. SCARSETH[2]

CONSIDERABLE work has been done in investigating the causes of boron starvation in plants in many areas of the United States. Several theories have been proposed and valuable information has been reported concerning the causes of boron starvation in plants.

Naftel (8)[3] studied the injurious effect of overliming and was the first to report this to be directly related to boron. He suggested that overliming might increase the growth of micro-organisms, which in turn would compete with the plants for the available boron of the soil.

Cook and Millar (1) found that beets growing on soils high in active calcium were much more likely to be boron deficient than if the active calcium were low, and they stated that factors of great importance affecting the boron supply were calcium, organic matter, and soil texture.

Midgley and Dunklee (6) found that as high as 90% of the boron added was fixed when a podzol A_1 horizon and Maine peat moss were overlimed; but they reported that boron added to limestone was not fixed, since both calcium and magnesium borates are relatively soluble.

Powers (9) showed, with greenhouse pot experiments on Oregon soils, that where lime was used, boron in some cases was less effective, and that where sulfur was used, the boron availability was somewhat improved. When high levels of calcium were used in growing oranges in sand cultures, Haas (3) found it necessary to add larger amounts of boron to prevent boron starvation.

Cook and Millar (1) reported calcium and magnesium carbonates to be effective in masking crop injury caused by excessive applications of boron; however, calcium and magnesium sulfates were only partially effective in fixing boron in forms not available to soybeans.

Ferguson and Wright (2) studied the effects of sodium and calcium borates in the nutrient solution on limed and unlimed sands. They found that boron starvation symptoms were common where the plants received calcium borate, and thereby concluded that boron deficiency troubles may be greater where calcium borate instead of sodium borate is used as the source of available boron.

EXPERIMENTAL PROCEDURE AND RESULTS

BORON FIXATION BY CLAY AND HUMUS AT VARIOUS PH LEVELS

One theory of overliming was that the soil fixed the boron at higher pH levels resulting from the heavy application of lime. It seemed

[1]Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Indiana. The authors wish to express appreciation to the American Potash Institute, Inc., for fellowship funds that made this work possible.

[2]Fellow in Agronomy; formerly Assistant Professor of Soil Chemistry at Purdue University, now Research Professor of Chemistry, Massachusetts State College, Amherst, Massachusetts; and Soil Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 461.

possible that the boron could be held on the colloidal complex by a mechanism similar to that advanced by Scarseth (10) for the fixation of the phosphate ion.

An electrodialized colloid isolated from a Miami soil was used for this test. Here 3.5 millimoles of H_3BO_3 per 100 grams of colloid (amounts equivalent to those used by Scarseth) were added to a closed system and 16 pH levels ranging from pH 4.1 to 11.5 were obtained by adding increments of $Ca(OH)_2$. The suspensions were shaken end over end for 24 hours, aliquots centrifuged, and boron analyses made on the centrifugate by the method of Truog and Berger (11). At every reaction all of the boron added was recovered (Table 1), showing that none was fixed by the clay fraction. Next an electrodialized humus extract from a Brookston silt loam soil was studied in the same manner and here again all the boron which had been added was recovered (Table 2).

TABLE 1.—*The influence of pH on the recovery of boron from a Miami colloid treated with varying quantities of calcium hydroxide.*

Sample No.	Ml $Ca(OH)_2$ added	pH	Boron added, millimoles*	Boron recovered, millimoles	Boron fixed, millimoles
1	0	4.1	0.055	0.055	None
2	5	4.7	0.055	0.055	None
3	10	5.1	0.055	0.055	None
4	15	5.5	0.055	0.055	None
5	20	6.9	0.055	0.055	None
6	25	7.4	0.055	0.055	None
7	30	9.2	0.055	0.055	None
8	35	10.1	0.055	0.055	None
9	40	10.5	0.055	0.055	None
10	45	10.8	0.055	0.055	None
11	50	11.0	0.055	0.055	None
12	55	11.1	0.055	0.055	None
13	60	11.2	0.055	0.055	None
14	65	11.3	0.055	0.055	None
15	70	11.4	0.055	0.055	None
16	75	11.6	0.055	0.055	None

*Boron was added as H_3BO_3 at the rate of 0.055 millimole per 1.59 grams of clay or 3.5 millimoles of H_3BO_3 per 100 grams of clay.

To make certain that the neutralizing action of the electrodialized soil colloids had not interfered with the formation of insoluble salts which might have resulted from a reaction between boric acid and calcium hydroxide, a third test was made in which the same quantities of boron were shaken with water containing quantities of $Ca(OH)_2$ equal to those which had been added to the inorganic soil colloid-boric acid systems. A complete recovery of boron was made from each solution regardless of its pH or calcium concentration. It is concluded, therefore, that boron is not fixed by the soil humus or by the clay fraction and is not rendered insoluble by the calcium in the soil.

RECOVERY OF BORON FROM A LIMED SOIL

In order to determine how much boron was fixed in a common Corn Belt soil, to each of a set of half-pint tumblers were added 200

grams of Crosby silt loam soil containing 0.3 p.p.m. of water-soluble boron as determined by the Truog and Berger method (11). There were four series in the set, and all treatments were made in duplicate. The soil in duplicate tumblers was limed with C.P. $CaCO_3$ at 0, 1/8, 1/4, 1/2, 1, and 2 times the lime requirements as determined by the Naftel method (7). The first series was untreated except that it received lime at the above rates; the second series received 2 p.p.m. of boron and lime; the third series received 0.05 gram of $NH_4H_2PO_4$, 0.05 gram of NH_4NO_3, and 5 grams of mannitol and lime; and the fourth series received in addition to the materials of the third series an application of 2 p.p.m. of boron as boric acid. The nitrogen, phosphorus, and mannitol were added to stimulate the development of micro-organisms in order to determine if these organisms fix boron at these various rates of liming.

TABLE 2.—*Influence of pH on the recovery of boron from a humus extract treated with varying quantities of calcium hydroxide.*

Sample No.	Ml $Ca(OH)_2$ added	pH	Boron added, millimoles*	Boron recovered, millimoles	Boron fixed, millimoles
1	0	3.8	0.055	0.055	None
2	2.5	4.3	0.055	0.055	None
3	5.0	5.1	0.055	0.055	None
4	6.0	5.7	0.055	0.055	None
5	7.0	6.0	0.055	0.055	None
6	8.0	6.4	0.055	0.055	None
7	8.5	6.6	0.055	0.055	None
8	9.0	6.8	0.055	0.055	None
9	9.5	7.1	0.055	0.055	None
10	10.0	7.4	0.055	0.055	None
11	10.5	7.9	0.055	0.055	None
12	12.0	8.6	0.055	0.055	None
13	15.0	9.9	0.055	0.055	None
14	20.0	10.7	0.055	0.055	None
15	30.0	11.3	0.055	0.055	None
16	40.0	11.5	0.055	0.055	None

*Boron was added as H_3BO_3 at the rate of 0.055 millimole of H_3BO_3 per 0.116 gram of humus.

The soils were aerated by forcing air through inserted glass tubes and were brought to optimum moisture two times each week for a period of 10 weeks. The water-soluble boron was determined at the end of this period by the Truog and Berger method (11) and by a modification of this method in which 50 grams of soil and 100 cc of distilled water were shaken 24 hours instead of boiling with a reflux condenser. This modification was made in an attempt to prevent any release of boron that might have been held by the micro-organisms and which might be released upon boiling.

Where no boron was added (Table 3), as much boron was extracted from the soil both with and without the nitrogen, phosphorus, and mannitol treatment as was obtained from this soil when brought from the field. Approximately 90% of the 2 p.p.m. of boron added was recovered by the Truog and Berger method (11) and 60% by the modified method. The calcium supply and the nitrogen, phosphorus,

and mannitol added did not appreciably affect the amount of boron recovered, although there was some indication that part of the boron added became less available.

TABLE 3.—*The effect of liming and nutrients on the quantity of boron recovered from a Crosby silt loam soil.*

Boron recovered in p.p.m.					
Without N, P, or mannitol			With N, P, and mannitol		
pH	Truog method	Modified method	pH	Truog method	Modified method
No Boron Added*					
5.3	0.3	0.25	5.5	0.35	0.3
5.5	0.3	0.3	5.9	0.4	0.25
5.8	0.35	0.25	6.1	0.4	0.25
6.1	0.35	0.3	6.5	0.4	0.3
6.8	0.3	0.3	6.8	0.4	0.3
7.8	0.3	0.3	7.9	0.4	0.25
2 p.p.m. of Boron Added*					
5.4	2.0	1.4	5.7	1.8	1.3
5.6	2.3	1.3	6.2	1.8	1.3
5.8	2.3	1.3	6.5	2.0	1.3
6.2	2.4	1.2	6.8	2.0	1.4
6.7	2.4	1.2	7.2	2.4	1.4
7.8	2.0	1.2	7.9	2.0	1.3

*0.3 p.p.m. in soil originally.

EFFECT OF CALCIUM SUPPLY ON BORON INTAKE OF PLANTS

In order to determine the effect of calcium on the boron content of plants, gallon pots of silica sand were set up in duplicate and supplied with Hoagland and Broyer (5) nutrient solutions which did not contain boron except as an impurity in the reagent quality chemicals. The solutions were modified, one series being adjusted to 0.0025 molar in calcium and the other 0.025 molar. Further modification was made in that the pH of these solutions, as measured by the glass electrode, was adjusted to 4.4 by adding HCl, and to 5.2, 6.0, 6.8, and 7.6 by adding NaOH.

Corn and tobacco plants were grown in these solutions for 3 weeks, using eight plants per pot. After 3 weeks, four of the plants were removed from each pot and the remaining four plants were treated for 4 days with Hoagland and Broyer nutrient solution to which 1 p.p.m. of boron had been added. In each case the entire plant was removed, washed with distilled water, and dried at 100°C for analysis. Ash analysis (Table 4) showed that neither the altering of the solutions by adjusting the pH, nor the amount of calcium supplied affected the uptake of boron by these plants. All plants receiving the 4-day treatment with 1 p.p.m. of boron increased two to three fold in boron content; therefore, neither the active calcium nor pH affected the uptake of boron.

grams of Crosby silt loam soil containing 0.3 p.p.m. of water-soluble boron as determined by the Truog and Berger method (11). There were four series in the set, and all treatments were made in duplicate. The soil in duplicate tumblers was limed with C.P. $CaCO_3$ at 0, 1/8, 1/4, 1/2, 1, and 2 times the lime requirements as determined by the Naftel method (7). The first series was untreated except that it received lime at the above rates; the second series received 2 p.p.m. of boron and lime; the third series received 0.05 gram of $NH_4H_2PO_4$, 0.05 gram of NH_4NO_3, and 5 grams of mannitol and lime; and the fourth series received in addition to the materials of the third series an application of 2 p.p.m. of boron as boric acid. The nitrogen, phosphorus, and mannitol were added to stimulate the development of micro-organisms in order to determine if these organisms fix boron at these various rates of liming.

TABLE 2.—*Influence of pH on the recovery of boron from a humus extract treated with varying quantities of calcium hydroxide.*

Sample No.	Ml $Ca(OH)_2$ added	pH	Boron added, millimoles*	Boron recovered, millimoles	Boron fixed, millimoles
1	0	3.8	0.055	0.055	None
2	2.5	4.3	0.055	0.055	None
3	5.0	5.1	0.055	0.055	None
4	6.0	5.7	0.055	0.055	None
5	7.0	6.0	0.055	0.055	None
6	8.0	6.4	0.055	0.055	None
7	8.5	6.6	0.055	0.055	None
8	9.0	6.8	0.055	0.055	None
9	9.5	7.1	0.055	0.055	None
10	10.0	7.4	0.055	0.055	None
11	10.5	7.9	0.055	0.055	None
12	12.0	8.6	0.055	0.055	None
13	15.0	9.9	0.055	0.055	None
14	20.0	10.7	0.055	0.055	None
15	30.0	11.3	0.055	0.055	None
16	40.0	11.5	0.055	0.055	None

*Boron was added as H_3BO_3 at the rate of 0.055 millimole of H_3BO_3 per 0.116 gram of humus.

The soils were aerated by forcing air through inserted glass tubes and were brought to optimum moisture two times each week for a period of 10 weeks. The water-soluble boron was determined at the end of this period by the Truog and Berger method (11) and by a modification of this method in which 50 grams of soil and 100 cc of distilled water were shaken 24 hours instead of boiling with a reflux condenser. This modification was made in an attempt to prevent any release of boron that might have been held by the micro-organisms and which might be released upon boiling.

Where no boron was added (Table 3), as much boron was extracted from the soil both with and without the nitrogen, phosphorus, and mannitol treatment as was obtained from this soil when brought from the field. Approximately 90% of the 2 p.p.m. of boron added was recovered by the Truog and Berger method (11) and 60% by the modified method. The calcium supply and the nitrogen, phosphorus,

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Boron recovered in p.p.m.					
Without N, P, or mannitol			With N, P, and mannitol		
pH	Truog method	Modified method	pH	Truog method	Modified method
No Boron Added*					
5.3	0.3	0.25	5.5	0.35	0.3
5.5	0.3	0.3	5.9	0.4	0.25
5.8	0.35	0.25	6.1	0.4	0.25
6.1	0.35	0.3	6.5	0.4	0.3
6.8	0.3	0.3	6.8	0.4	0.3
7.8	0.3	0.3	7.9	0.4	0.25
2 p.p.m. of Boron Added*					
5.4	2.0	1.4	5.7	1.8	1.3
5.6	2.3	1.3	6.2	1.8	1.3
5.8	2.3	1.3	6.5	2.0	1.3
6.2	2.4	1.2	6.8	2.0	1.4
6.7	2.4	1.2	7.2	2.4	1.4
7.8	2.0	1.2	7.9	2.0	1.3

*0.3 p.p.m. in soil originally.

EFFECT OF CALCIUM SUPPLY ON BORON INTAKE OF PLANTS

In order to determine the effect of calcium on the boron content of plants, gallon pots of silica sand were set up in duplicate and supplied with Hoagland and Broyer (5) nutrient solutions which did not contain boron except as an impurity in the reagent quality chemicals. The solutions were modified, one series being adjusted to 0.0025 molar in calcium and the other 0.025 molar. Further modification was made in that the pH of these solutions, as measured by the glass electrode, was adjusted to 4.4 by adding HCl, and to 5.2, 6.0, 6.8, and 7.6 by adding NaOH.

Corn and tobacco plants were grown in these solutions for 3 weeks, using eight plants per pot. After 3 weeks, four of the plants were removed from each pot and the remaining four plants were treated for 4 days with Hoagland and Broyer nutrient solution to which 1 p.p.m. of boron had been added. In each case the entire plant was removed, washed with distilled water, and dried at 100°C for analysis. Ash analysis (Table 4) showed that neither the altering of the solutions by adjusting the pH, nor the amount of calcium supplied affected the uptake of boron by these plants. All plants receiving the 4-day treatment with 1 p.p.m. of boron increased two to three fold in boron content; therefore, neither the active calcium nor pH affected the uptake of boron.

TABLE 4.—*Comparison of the boron content of corn and tobacco plants grown in sand cultures supplied with Hoagland and Broyer's nutrient solution both with and without added boron.*

Sample No.	pH of solution	Molar concentration of Ca in solution	Boron content of plants*	
			Grown without boron, p.p.m. B	Grown with boron, p.p.m. B
		Corn		
1	4.4	0.0025	6	20
2	5.2	0.0025	6	20
3	6.0	0.0025	6	21
4	6.8	0.0025	6	24
5	7.6	0.0025	6	22
6	4.4	0.025	6	21
7	5.2	0.025	6	21
8	6.0	0.025	6	22
9	6.8	0.025	6	20
10	7.6	0.025	6	22
		Tobacco		
11	4.4	0.0025	11	20
12	5.2	0.0025	12	24
13	6.0	0.0025	12	24
14	6.8	0.0025	12	22
15	7.6	0.0025	12	24
16	4.4	0.025	9	26
17	5.2	0.025	11	22
18	6.0	0.025	10	22
19	6.8	0.025	10	23
20	7.6	0.025	12	25

*Four plants were harvested from each pot at the end of 3 weeks. For 4 days the remaining four plants received the nutrient solution to which had been added 1 p.p.m. of boron.

CALCIUM-BORON RATIO OF TURKISH TOBACCO IN RELATION TO BORON STARVATION

In 1939, Turkish tobacco plants grown in greenhouse pots on Norfolk sand (Fig. 1) developed characteristic boron-starvation symptoms with certain treatments, although the boron treatment was the same for all pots. All plants were grown with low amounts of boron, and in all cases where boron-deficiency symptoms were observed there was also a high calcium content in the ash of the plants. Where the higher concentration of the sulfate ion was present, the calcium absorption by the plant was lower and a more favorable balance was maintained between calcium and boron within the plant.

Although the boron content of the plant ash was as high in those plants showing boron-starvation symptoms as in the plants that appeared normal, the calcium content of the plant ash was higher in the boron-starved plants than in the plants with normal appearance. The normal plants had a calcium-boron ratio not exceeding 1,340:1, while the boron-deficient plants had ratios ranging from 1,500:1 to 2,100:1. The data in Table 5 present an interesting example of the

importance of the calcium-boron ratio in the plant. Turkish tobacco plants were grown in 1940 in sand cultures without boron in order to verify the boron-deficiency symptoms and those plants with dying terminal buds recovered when 1 p.p.m. of boron was added.

FIG. 1.—Turkish tobacco plants grown in greenhouse pots on Norfolk sand, showing the boron deficiency symptoms on the left and normal growth on the right. Flower buds were removed from the normal plants on the right. Soil treatment: Left, NH_4NO_3; 0.48 gram of SO_4 added as $MgSO_4$. Right, $(NH_4)_2SO_4$; 1.58 grams of SO_4 added as $MgSO_4$ and $(NH_4)_2SO_4$. Plant analysis: Left, 7,600 p.p.m. Ca; 5 p.p.m. B; Ca/B = 1,520:1. Right, 5,100 p.p.m. Ca; 4 p.p.m. B; Ca/B = 1,275:1.

DISCUSSION

Powers (9) found that sulfur increased the effectiveness of boron in Oregon soils. Hoagland (4) has shown that the sulfate ion depresses calcium and magnesium absorption. It appears, therefore, that sulfur, by retarding the uptake of calcium by the plant, prevented the calcium-boron ratio from becoming unfavorable. Ferguson's suggestion (2) that calcium borate was more likely to cause boron starvation than was sodium borate when used in growing plants in sand cultures may be explained in that the sodium borate did not increase the concentration of calcium in the plant, thereby keeping the calcium-boron ratio more favorable.

The work of Haas (3) in which he found it necessary to add more boron when high calcium levels were used, and the findings of Cook and Millar (1) in which they state that high levels of active calcium in the soil are very important in causing boron deficiency, greatly strengthen the authors' hypothesis that the concentrations of calcium and boron in the plant must be in a favorable ratio.

The ratios as shown by the experiment with Turkish tobacco indicate that 1,340 parts of calcium to 1 part of boron was favorable,

TABLE 5.—*Effect of calcium-boron ratio of tobacco plants on the appearance of boron-deficiency symptoms.*

Basic treatment*	Grams of SO_4 per treatment	Dry weight of plants, grams	Plant analysis			Growth
			Ca, p.p.m.	B, p.p.m.	Ca/B ratio	
No lime, $MgSO_4$, $(NH_4)_2SO_4$	1.58	36.7	5,100	4	1,275:1	Normal appearance
No lime, $MgSO_4$, NH_4NO_3	0.48	28.0	7,600	5	1,520:1	Boron deficient
Lime, $MgSO_4$, $(NH_4)_2SO_4$	1.58	32.2	6,700	5	1,340:1	Normal appearance
Lime, $MgSO_4$, NH_4NO_3	0.48	33.0	7,500	5	1,500:1	Boron de - cient
No lime, 100-mesh Dolomite	1.10	35.4	6,000	4½	1,330:1	Normal appearance
Lime, 100-mesh Dolomite	1.10	30.9	9,500	4½	2,100:1	Boron de - cient

*All pots received 3 grams of KCl and 1.8 grams of $CaHPO_4$.
$(NH_4)_2SO_4$ = 1.5 grams.
$MgSO_4$ = 1.23 grams.
Lime = 1 gram $CaCO_3$.
Dolomite = 1.03 grams.

and that the ratio of 1,500:1 was unfavorable for the normal growth of this crop. Further investigation will be made with tobacco and other plants to determine the ratio of calcium to boron in the plant ash when boron is toxic, when growth is normal, and when the plant shows boron starvation symptoms.

On the basis that the physiological relationship of calcium to boron is similar in other plants as shown here for tobacco, it would appear that soils known to be high in available calcium should be suspected of producing boron-deficient plants unless proved otherwise, as the plants grown thereon would be expected to have a high calcium-boron ratio in the plant ash. Lowly buffered soils frequently show boron starvation just after being limed, but as the active calcium is leached out of the surface soil or is brought into equilibrium with the soil acid, the deficiency appears to vanish. As the free calcium decreases, the calcium-boron ratio becomes more favorable and the crops produced show less evidence of boron starvation.

If analyses on the plant ash show the plant to be high in calcium and low in boron, experiments using boron should be conducted, for even though there may have been no external evidences of boron starvation, the calcium-boron ratio in the plant may have been unfavorable for optimum plant growth. Undoubtedly the most favorable calcium-boron ratio for different kinds of plants will vary. Further investigation should determine this point, as well as the ratios at which boron is toxic and where it is deficient.

SUMMARY

In order to determine if boron is fixed by the soil colloid in a manner similar to the fixation of the phosphate ion, portions of an electrodialized colloid from a Miami soil and an electrodialized humus extract from a Brookston loam were adjusted to 16 pH levels, ranging from pH 4.1 to 11.5. Three and one-half millimoles of H_3BO_3 per 100 grams of colloid were added, the suspensions shaken 24 hours, aliquots centrifuged, and boron determined by the method of Truog and Berger (11). All of the boron added was recovered in all cases. The same quantities of boron were shaken with water containing amounts of $Ca(OH)_2$ equal to those added to the inorganic soil colloid-boric acid systems. All the boron was recovered from each of the solutions regardless of its pH or calcium concentration. From this it was concluded that boron is not absorbed by the clay or humus complexes, or made insoluble with calcium.

Four series of samples of a Crosby silt loam soil were limed at 0, ⅛, ¼, ½, 1, and 2 times the lime requirement. One series did not receive boron or nutrients (nitrogen, phosphorus, and mannitol), a second received 2 p.p.m. of boron, a third received nutrients, and the fourth received 2 p.p.m. of boron and nutrients. At the end of 10 weeks, analysis for available boron showed that neither the calcium supply nor the added nitrogen, phosphorus, and mannitol, affected the amount of boron recovered, although there was an indication that a small part of the added boron becomes less available since all of the boron added was not recovered.

Corn and tobacco plants were grown in pots containing silica sand to which was added a nutrient solution. The solution did not contain boron, except as an impurity in the chemicals. The solution was modified to make one series 0.0025 molar and the other 0.025 molar in calcium. The pH of these solutions was adjusted to range from 4.4 to 7.6. After 3 weeks, four of the plants were removed from each pot and the remaining four were treated 4 days with nutrient solution containing 1 p.p.m. boron. Neither the active calcium nor the pH affected the uptake of boron by these plants.

The growth of Turkish tobacco grown on a Norfolk sand in greenhouse pots appeared normal when the calcium-boron ratio in the plants did not exceed 1,340:1. A calcium-boron ratio of 1,500:1 in the plants was correlated with severe boron starvation symptoms.

The information reported here, together with results of other investigators, indicate that boron starvation results when the calcium-boron in the plant becomes unfavorable. Undoubtedly the most favorable calcium-boron ratio for different kinds of plants will vary. Further investigation should determine this as well as the ratios at which boron is toxic and where it is deficient.

It appears that there is a possibility of using these ratios of calcium to boron in the plant as a guide in determining the need of boron fertilization.

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GENETIC STUDIES OF REACTIONS TO SMUT AND OF FIRING IN MAIZE BY MEANS OF CHROMOSOMAL TRANSLOCATIONS[1]

LEWIS C. SABOE AND H. K. HAYES[2]

IT is generally appreciated that there are wide differences among inbred lines of corn in their reaction to smut, *Ustilago zeae* (Beck.) Ung., certain inbreds being much more resistant than others, some inbreds being high susceptible. As smut often causes marked reductions in yield of grain, the problem of breeding smut-resistant hybrids is an important one. Dr. E. G. Anderson has suggested the use of translocations, also called interchanges in this paper, in the study of the linkage relations of complex characters and has furnished such interchanges from the interchange stocks that he has available.

The present paper presents information regarding the genetics of smut reaction in crosses of two smut-resistant inbred lines from the breeding program at University Farm, St. Paul, Minn., with smut-susceptible interchange lines obtained from Dr. Anderson.

REVIEW OF LITERATURE

Jones (12)[3] presented evidence in 1918 that some inbred lines of corn were much more resistant to the smut fungus, *Ustilago zeae* (Beck.) Ung., than others and various investigators (7, 8, 13) have shown that it is relatively easy to isolate smut-resistant lines by selection in self-fertilized lines.

The known linkage groups have been used by Immer (10) and Hoover (9) to study the inheritance of smut reaction in crosses between inbred lines of maize that differ widely in smut infection. Linkage was observed between the Pp factor pair and smut reaction, also associations were found between susceptibility and such morphological characters as liguleless, brachytic, ramosa, and tassel seed, which may be more favorable for the entrance of the smut organism because of their morphology.

Chromosomal translocations were utilized by Burnham and Cartledge (5) to study the inheritance of smut reaction in maize. Considering odds of 19:1 as a significant deviation for errors of random sampling, they observed associations between smut reaction and the point of interchange in crosses between a highly smut-resistant line with the smut susceptible interchange lines 1–2c, 1–6a, 1–9b, 2–3a, 2–4d, 2–6a, 3–5a, 3–7b, 3–8a, 3–10a, 4–9a, 6–8a, and 9–10a.

Brink and Burnham (4) found that crosses between normal and semisterile maize plants gave equal numbers of normal and semisterile offspring. As far as is known, chromosomal translocations produce neither morphological nor physiological expressions which favor the entrance of the pathogen.

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[3]Figures in parenthesis refer to "Literature Cited", p. 470.

MATERIALS AND METHODS

Two smut-resistant lines, one selected from Minn. No. 13 and the other from Rustler, selfed 8 and 11 generations, respectively, were used as resistant parents in these crosses. Crosses between these two lines and smut-susceptible lines in linkage group I have been studied previously by one of the writers. In these studies the linkage testers used were P, red pericarp, previously found to be associated with smut reaction by Immer (10); f, fine stripe; v, virescent seedling; and br, brachytic. Studies of association were made in the F_2 generation and in backcrosses to the susceptible parents without obtaining any evidence of a linkage relation. In these studies the smut epidemic was relatively satisfactory and from 300 to 700 plants were classified for smut reaction in each of the various crosses.

The percentage of smutted plants in 1937 for the inbred lines and interchange stocks used in the present study and similar data for 1938 for the inbred lines and F_1 crosses of inbred × interchange lines are given in Table 1. According to these data the interchange stocks were very susceptible as compared to the inbred lines. F_1 plants were intermediate in percentage of infection.

TABLE 1.—*Percentage of smutted plants in resistant inbred lines, interchange stocks, and F_1 crosses for 1937 and 1938.*

Pedigree	Per cent smut 1937	Pedigree	Per cent smut 1938	Pedigree	Per cent smut 1938
Rustler Inbred	7.83	Rustler Inbred	1.35		
Minn. No. 13 Inbred	17.03			Minn. No. 13 inbred	1.83
1–4a	80.00	Inbred × 1–4a	8.20	Inbred × 1–4a	14.91
1–9c	82.61	Inbred × 1–9c	31.25	Inbred × 1–9c	12.90
1–10a	81.81	Inbred × 1–10a	2.40	Inbred × 1–10a	13.60
2–4b	65.38	Inbred × 2–4b	11.67	Inbred × 2–4b	29.51
3–5c	97.62	Inbred × 3–5c	29.31	Inbred × 3–5c	22.03
3–7b	89.47	Inbred × 3–7b	28.12	Inbred × 3–7b	23.33
4–6a	78.57			Inbred × 4–6a	16.67
5–7d	93.33	Inbred × 5–7d	14.52	Inbred × 5–7d	24.19
5–8a	92.86	Inbred × 5–8a	21.28	Inbred × 5–8a	23.33
6–9a	52.38	Inbred × 6–9a	40.00	Inbred × 6–9a	30.77
8–10a	92.11	Inbred × 8–10a	28.41	Inbred × 8–10a	25.60

Cytological and genetical data made available by Dr. E. G. Anderson for these interchanges are given in Table 2.

The interchanges used in this study, described in Table 2, are distributed in 15 arms of the 10 chromosomes; the short arms of the chromosomes 2, 7, 8, and 9, and the long arm of 10 not being included. Each interchange may be considered to test a portion of the chromosome not exceeding 40 to 50 genetic units on either side of the break locus. For some interchanges where only genetical data were available, the position of the breaks is in relation to known genetic factors. Where cytological information regarding the location of the interchange was used, Anderson stated that the position of the break might vary as much as 0.2 of the length of the arm involved.

The Rustler inbred line was homozygous for an intervascular firing character showing up in the leaves and studies of the inheritance of this character were made also by the use of chromosomal translocations.

Semisterile plants were crossed with each of the two resistant inbred lines and semisterile F_1 plants were backcrossed to the resistant inbred parent. Since the

F_1 plants were intermediate in smut reaction, it appeared possible to differentiate backcross plants heterozygous for smut reaction from those homozygous for smut resistance.

TABLE 2.—*Chromosomal interchanges used together with cytological and genetical data on the position of the breaks (T).*

Inter-change	Position of breaks in chromo-somes		Position of break loci (T) in corresponding genetic maps		Data source
1–4a	1L.6*	4S	br–20–T† –45–bm_2	Near Ts_5 and su (T–O–Ts_5)	‡
1–9c	1S.6	9L.2	ts_2–P–1.0–T	wx–12.1 to 12.7–T	‡
1–10a	1L.4		near br	T–15–g_1–R	‡
2–4b	2L.6	4L.8	B–ts_1–v_4–5.6–T	su–Tu–gl_3–15–T	‡
3–5c			na_1–11.7–T–12.5–a	near pr_1	‡
3–7b	3S.8	7L.1	(T–27.3–ts_4)(d_1±0.4–T)	near ra_1	‡
4–6a	4L.2	6L.2	su–4.5–T–14.6–Tu	very near Y_1	‡
5–7d			near a_2	near ra_1	‡
5–8a				T–4–ms_8–8.5–j_1	(3)**
6–9a	6S§	9L.3	T–4.9 to 17.3–Y–16.2 to 25.8–Pl	C–wx–9.4–T	(1, 2)
8–10a	8L.6	10S.3	(T–15–ms_8) (T–ms_8–j_1) (j_1±25.5–T)	T–17.0–g_1	‡(3)

*1L.6 means the break in chromosome 1 is in the long arm (L) 0.6 of the distance from the spindle attachment region to the end of the long arm.

†"T" refers to point of interchange, being 20 genetic units from br and 45 genetic units from bm_2.

‡Anderson, E. G., unpublished data.

§Within reticulated region.

**Figures in parenthesis refer to "Literature Cited", p. 470.

Semisterile plants were selected in the field by examining the pollen with a pocket microscope (Taschen Mikroskop). As the plants were classified as normal and semisterile they were marked by looping a rather long string (about 30 inches) around the main stalk at a convenient distance from the ground using a thin string for semisteriles and a heavy string for normals. This made it unnecessary to assign a number to each plant in the field.

In 1939, the backcrossed seed was planted in a plot which had been used for smut trials for many years. One seed per hill was planted, with hills 1 foot apart, in rows 132 feet in length. Five rows were planted of each interchange-inbred backcross. As each row was planted from a different ear, studies of association with each of the interchanges represented five separate pollinations.

No artificial inoculations were made since this smut plot has been used for smut studies for the past 12 years and had sufficient inoculum in the soil to produce a satisfactory epidemic, as evidenced by susceptible varieties approaching 100% smut infection.

The classification of plants for sterility was done just as soon as the anthers were ready to dehisce. From 6 a.m. until about 11 a.m. proved to be the best time for classification. Smut notes were taken but once during the latter part of August when a major portion of infection was discernible. At this time tassel, main stalk, sucker, and ear infections were present.

There was some variation in the expression of firing for the Rustler inbred parent and not all plants exhibited the fired character at the same stage of development, although it appeared usually shortly after silking of the plant. In

the hybrids the plants were classified for firing after they had been classified for pollen sterility and before there was general drying of the leaves due to maturity.

Plants that were definitely fired were marked by tying a knot on the string used to mark the semisterile and normal plants. When classification of the plants for sterility and firing was completed, the number of plants in each class was then recorded.

The cultures for one interchange were all planted together since each culture was a unit within itself. In order to determine the significant associations, the X^2 test for independence, as outlined by Fisher (6) was used.

EXPERIMENTAL RESULTS

ASSOCIATION BETWEEN SMUT REACTIONS AND POINTS OF INTERCHANGE

Table 3 summarizes the data obtained in 1939 from the backcross progenies to the resistant parents. The number of smutted and smut-free plants in both the normal and semisterile classes, the total number of plants, and the corresponding P values for a X^2 test for independence are given for each of the crosses between the resistant parents with the various susceptible interchanges.

From the data given in Table 1 the interchange stocks are much more smut susceptible than are the resistant inbred parents. The F_1

TABLE 3.—*Summary of data of progenies from crosses of susceptible interchanges × resistant inbred lines (Minn. No. 13 and Rustler) and backcrossed to resistant parent, 1939.*

Inter-change	Normal		Semisterile		Total plants	P value
	Not smutted	Smutted	Not smutted	Smutted		
			Minn. No. 13			
1–4a	189	53	203	63	508	0.50 –0.70
1–9c	191	66	191	86	534	0.10 –0.20
1–10a	154	61	169	85	468	0.20 –0.30
2–4b	172	54	207	90	523	0.10 –0.20
3–5c	163	44	248	86	541	0.20 –0.30
3–7b	236	55	182	78	551	0.001–0.01
4–6a	195	52	227	72	546	0.30 –0.50
5–7d	185	57	152	90	484	0.001–0.01
5–8a	248	50	205	57	560	0.10 –0.20
6–9a	212	58	185	99	554	<0.001
8–10a	200	64	195	109	568	0.001–0.01
			Rustler			
1–4a	170	13	260	39	482	0.02 –0.05
1–9c	219	31	177	34	461	0.20 –0.30
1–10a	216	16	195	22	449	0.20 –0.30
2–4b	213	17	216	20	466	0.50 –0.70
3–5c	226	23	168	33	450	0.02 –0.05
3–7b	232	29	235	36	532	0.30 –0.50
5–7d	177	20	232	25	454	0.80 –0.90
5–8a	233	16	198	32	478	0.001–0.01
6–9a	152	26	85	14	277	0.90 –0.95
8–10a	196	25	211	33	465	0.30 –0.50

generation was intermediate in smut reaction. In cases of association between semisterility and smut reaction there would be a greater percentage of smutted plants in the semisterile class than in the normal class.

Significant deviations from independent assortment, with a P value less than .01, were observed in crosses with the interchanges 3–7b, 5–7d, 6–9a, and 8–10a when the resistant Minnesota No. 13 inbred line was used as the recurrent parent. When the resistant Rustler inbred line was used as the recurrent parent, significant deviations from independence were obtained in crosses with the interchanges 1–4a, 3–5c, and 5–8a. Deviations from independent assortment exceeded the .01 value in crosses with 5–8a and fell between a value of P equals .02–.05 for the two other crosses.

These associations would indicate that there were several factor pairs or linked groups of factors responsible for smut reactions in the crosses between the susceptible interchange stocks with both the Rustler and the Minn. No. 13 resistant inbred lines.

It is evident also that the factors for smut reaction were not the same for these two inbred lines. It is of interest to point out that the associations in these crosses are different than those reported by Burnham and Cartledge.

Since semisterility can be recognized in the heterozygous condition, it was not always possible, without data from additional interchanges, to determine which chromosome of the two involved in an interchange is concerned in the linkage with smut reaction as either one of the chromosomes, or both, may carry the loci for smut reaction. It was possible in several cases to determine which of the chromosomes was involved in the linkage by utilizing other interchanges with breaks close to the original one.

In the backcrosses with the inbred smut-resistant parent from Minn. No. 13 with the various interchanges, interchange 6–9a showed a significant association with smut reaction. From this alone it would be impossible to determine whether it was the portion of chromosome 6 adjacent to the break, or the portion of chromosome 9 adjacent to the break or both, that were responsible for the association observed. In the same study interchange 1–9c showed no significant association with smut reaction. The breaks in chromosome 9 of interchanges 1–9c and 6–9a are very close together. If that portion of chromosome 9 were involved with the smut reaction, associations should have been observed with both interchanges. Since such was not the case, it appears very probable that chromosome 6 was the one responsible for the significant association observed.

Significant association was observed with 8–10a but not with 1–10a. Since the genetic positions in chromosome 10 are very close together, it would indicate that chromosome 8 was responsible for the association.

Significant associations were observed with both 3–7b and 5–7d. The two breaks in chromosome 7 are very close together genetically which would suggest that it might be chromosome 7 that was concerned with the linkage observed.

From the above incomplete evidence, since all portions of the

chromosomes were not tested, the associations indicate that at least three factor pairs or linked groups of factors were responsible for the smut reaction in the Minn. No. 13 crosses. The suggested location of these factor pairs or linked groups of factors is as follows: In the short arm of chromosome 6, another one in the long arm of chromosome 8, and another one probably in the long arm of chromosome 7.

The same series of interchange lines, except the 4–6a line, were crossed with the smut-resistant Rustler inbred line. In these crosses a significant association was observed with interchange 1–4a but not with 1–10a. Since the breaks in chromosome 1 of interchanges 1–4a and 1–10a are fairly close, this would indicate that chromosome 4 was the one responsible for the association observed.

The breaks of the other interchanges showing significant associations were so widely separated from the breaks of the interchanges not showing association that the location of the linkages could not be determined with certainty. It would appear, however, that at least two, possibly three, factor pairs, or linked group of factors, seem to be responsible for the smut reaction in the Rustler cross. The possible location of each of these is as follows: One in the short arm of chromosome 4, another either in the long arm of chromosome 3 or in the long arm of chromosome 5, and another either in the long arm of chromosome 8 or somewhere in chromosome 5. Since the break locus in chromosome 5 of interchange 5–8a is not known, it is possible that the break in 5 might be very close to the break in 5 of the 3–5 interchange in which case linkage would be with the 5 locus in both cases.

ASSOCIATIONS BETWEEN THE FIRING CHARACTER AND POINTS OF INTERCHANGE

Table 4 summarizes the number of normal and fired plants in the normal and semisterile classes, the total number of plants, and gives P values for a study of independence for each of the backcrosses of the F_1 to the Rustler parent. Since the firing character came into the cross with the normal Rustler parent, more normal fired plants should be found than semisterile fired plants when associations are observed.

TABLE 4.—*Summary of data of progenies of interchanges × homozygous fired Rustler line backcross to fired parent, 1939.*

Interchange	Normal		Semisterile		Total plants	P value
	Not fired	Fired	Not fired	Fired		
1–4a	90	91	205	89	475	<0.001
1–9c	155	99	147	68	469	0.10
1–10c	158	75	160	60	453	0.20–0.30
2–4b	162	68	203	36	469	<0.01
3–5c	136	114	123	78	451	0.10–0.20
3–7b	151	110	179	83	523	0.01–0.02
5–7d	75	124	164	93	456	<0.001
5–8a	193	56	172	58	479	0.30–0.50
6–9a	144	32	78	19	273	0.30–0.50
8–10a	115	109	116	126	466	0.30–0.50

Significant associations were observed with 1–4a, 2–4b, 3–7b, and 5–7d. P values were less than .01 except for the interchange 3–7b with a P value between .01 and .02. This would indicate that several loci were concerned with the firing character.

Although Immer and Christensen (11) reported that the segregating of normal vs. fired gave a good fit to a 3:1 ratio in the F_2, their backcross data suggested a more complex inheritance. The firing character reported in this study may or may not be the same as that reported by Immer and Christensen. Several years ago Hayes[4] made several crosses between various inbreds, including two fired inbreds from Rustler with the lines used by Immer and Christensen, and found firing in all lines to be due to the same genetic factors. It has not been determined, however, that the fired line used in this study belongs to the same genotype.

The breaks in chromosome 1 of 1–4a and 1–10a are fairly close together. Since no association was observed with 1–10a, it is probable that it was chromosome 4 of the 1–4a interchange that was responsible for the observed association.

Significant associations were observed with both 3–7b and 5–7d. The breaks in chromosome 7 are very close, which would suggest that chromosome 7 might be the one responsible for the association.

At least three factor pairs or linked groups of factors seem to be responsible for the firing character; these may be located, one in the short arm of chromosome 4, another one either in the long arm of chromosome 2 or in the long arm of chromosome 4, and another one probably in the long arm of chromosome 7.

SUMMARY

1. F_1 crosses between smut-susceptible interchange lines and two resistant inbred lines derived from Rustler and Minnesota No. 13 were backcrossed to the resistant inbred parents. Linkage relations between the point of interchange and smut reaction were studied in the backcross progeny.
2. Each interchange involves two non-homologous chromosomes and a plant heterozygous for an interchange shows sterility in one-half of the pollen grains and ovules. The interchanges used in this study explore to a limited extent 15 arms of the 10 chromosomes; the short arms of chromosomes 2, 7, 8, and 9, and the long arm of chromosome 10 are not included.
3. Significant associations of smut reaction and point of interchange were observed with interchanges 3–7b, 5–7d, 6–9a, and 8–10a in the crosses with the inbred line of Minnesota No. 13, and with interchanges 1–4a, 3–5c, and 5–8a in the Rustler crosses.
4. In the Minnesota No. 13 crosses indications are that at least three factor pairs or linked groups of factors are responsible for the smut reaction; one possibly located in the long arm of chromosome 7, one in the short arm of chromosome 6, and one in the long arm of chromosome 8.

[4]Unpublished data.

5. In the Rustler crosses at least two, possibly three, factor pairs or linked groups of factors seem to be responsible for the smut reaction; one possibly located in the short arm of chromosome 4, one either in the long arm of chromosome 3 or in the long arm of chromosome 5, and one either in the long arm of chromosome 8 or somewhere in chromosome 5. The location of factors for smut resistance in the Rustler inbred seem to be different from those in the Minnesota No. 13 inbred.
6. The Rustler smut-resistant inbred line was also homozygous for a firing character. The linkage relations of this firing character and points of interchange were studied in a manner similar to the study of smut reaction. Significant associations of the firing character and interchanges 1–4a, 2–4b, 3–7b, and 5–7d were observed.
8. At least three factor pairs or linked groups of factors seem to be responsible for the firing character; one possibly located in the short arm of chromosome 4, one in the long arm of chromosome 7, and one either in the long arm of chromosome 2 or in the long arm of chromosome 4.

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NOTES

THE PARTRIDGE PEA, *CHAMAECRISTA FASCICULATA*, A PROMISING PLANT FOR SOIL CONSERVATION

THE partridge pea, *Chamaecrista fasciculata*, (Michx) Greene, a native legume of the eastern United States, was used both as a cover crop and as a forage crop 140 to 70 years ago but has been neglected in recent years. Preliminary tests by the Soil Conservation Service in Alabama indicate that this species may be useful on certain soils in the Southeast as a soil-conserving crop.

It has been sowed successfully on idle crop land, in orchards, on small grain, and in alternate rows with corn. Successful reseeding has occurred in each situation.

Chamaecrista fasciculata has several characteristics needed by the ideal soil-conserving crop in the Southeast. It will grow well on poor soil, its seedlings withstand frost well, its vegetation is not toxic to farm animals, and it competes well with weeds. *C. fasciculata* has a marked ability to reseed itself and will maintain itself on an area in competition with other vegetation for a number of years if undisturbed (Fig. 1). The seeds are relatively hard and will winter over in the soil with ease. They germinate over a long period the following spring. Harvested seed, however, may be sown in the spring with good results without having been scarified.

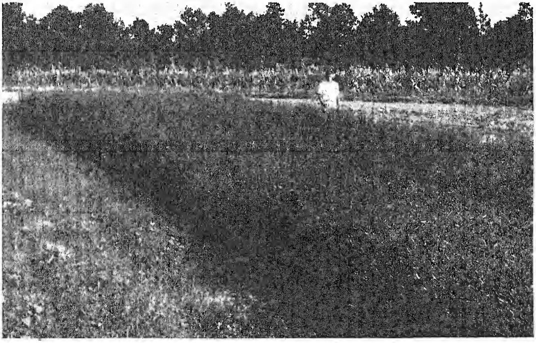

FIG. 1.—Plot of partridge pea seeded March, 1938. Photograph shows volunteer stand in 1939, giving a complete and thoroughly satisfactory ground cover.

Seed crops are usually large but difficult to gather because of a long, uneven maturity date, and a strong tendency for each pod to pop or shatter soon after maturity. Seed collections have been successful by cutting the plants when most of the seed are in the dough stage,

drying the plants on a tarpaulin or floor, and threshing them. The cost of collecting seed has been high, but, fortunately, low rates of seeding have been satifactory.

A good stand of *Chamaecrista fasciculata* makes an abundance of soil cover during the summer. The shattered leaves and pods provide excellent cover during the winter. Yields of green material have ranged up to 10,437 pounds per acre.

Seedings made in later winter have produced the largest yields and the best soil-protecting cover; later seedings have shown significant decreases in yield of green material. Ten pounds of seed per acre have given good stands in broadcast seedings and 5 pounds per acre in alternate rows with corn.

The plant seems well adapted to a wide range of soil conditions, but doubtless will be most useful on the poorer sandy soils where other soil-conserving crops are less successful.

Some positive responses to fertilizer have been shown, particularly to phosphate and potassium.

Chamaecrista fasciculata is relatively free from insect pests and diseases, although a wilt disease of the stems and leaves has given some damage.—OZELL A. ATKINS and W. C. YOUNG, *U. S. Dept. of Agriculture Soil Conservation Service, Auburn, Alabama.*

NURSERY PLANTER[1]

THE interest shown in an endless-belt nursery planter by visiting field research workers at the Iowa Agricultural Experiment Station prompts the author to offer the accompanying description and information on its operation.

This planter, shown in Fig. 1, has combined precision in planting and speed of operation to a greater degree than any other nursery planter used at this station. It embodies some of the features of the seed dropper described by Burnett[2] and also utilizes the v-type rubber belt described by Kemp.[3]

The rubber belt operates on two pulleys, the front pulley being actuated by a chain drive from the front wheel of the planter. Slanting metal sides provide an increase in capacity of the belt when heavy rates of seeding of large-seeded species are planted and also protection from the wind as needed when planting seeds of light weight.

An adjustable gate (Fig. 2A) terminates the portion of the belt required to pass over the front pulley for particular length of row to be seeded. A given amount of seed, previously weighed or counted and placed in an envelope, is distributed evenly along this length of belt. As shown at Fig. 2 B, a roller ball valve prevents seed from rolling down into the shoe before the belt begins to turn and facilitates

[1]Contribution from the U. S. Regional Soybean Industrial Products Laboratory, U. S. Dept. of Agriculture, and the Farm Crops Subsection of the Iowa Agricultural Experiment Station, Ames, Iowa. Journal Paper No. J-852 of the Iowa Agricultural Experiment Station, project 186.

[2]BURNETT, L. C. A seed dropper for cereal nursery rows, Jour. Amer. Soc. Agron., 29: 419–420. 1937.

[3]KEMP, H. J. Mechanical aids to crop experiments. Sci. Agr., 15:488–506. 1935. The endless-belt type of seeder herein described was later equipped with a v-type rubber belt.

an even distribution of seed during planting. The use of the roller valve, which allows distribution of the seed near the mouth of the shoe, and the bicycle chain drive have minimized the lag in starting. Allowance of approximately 12 inches at the beginning of the row has proved adequate, providing the planter is pushed forward with a steady motion.

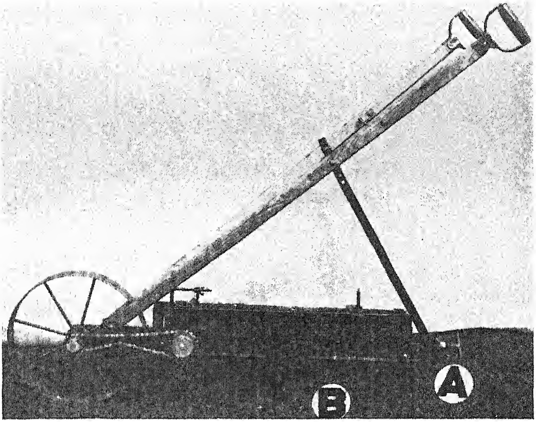

FIG. 1.—Endless-belt type nursery planter. A, belt tightener; B, split wheel.

Difficulty was encountered with the flat-belt type of planter when planting large, round seeds, such as soybeans or peas, in that any jolting or tilting of the planter caused the seeds to roll along the belt. With the v-type rubber belt this difficulty has been completely eliminated by devising a small stop (Fig. 2 C) which travels along the belt, preventing the seeds from rolling backward. The stop is prevented from entering the mouth of the shoe by a hook mounted on the planter frame. This stop must, of course, be moved back to the gate at the beginning of each row. A screw-type device (Fig. 1 A) on the rear "v" belt pulley permits adjustment of belt tension. A split covering wheel with beveled surfaces (Fig. 1 B) assures adequate covering of the seed.

One man can operate the planter satisfactorily when planting certain types of seed, such as most of the cereal crops, which lend themselves to easy distribution along the belt. The planter weighs 42.5 pounds and can easily be turned around at the end of the row by one man. When large seeded crops are planted and the moving stop is needed, or when seeds are planted which have a tendency to cling together, such as many of the awned forage crops, two men are re-

quired to operate the machine to full capacity. When planting cereal crops with optimum soil and weather conditions, 80 to 100 18-foot rows per hour are frequently planted by a single operator, providing the field has been marked previously. The planting of 100 to 120 rows per hour is possible when two operators are used.

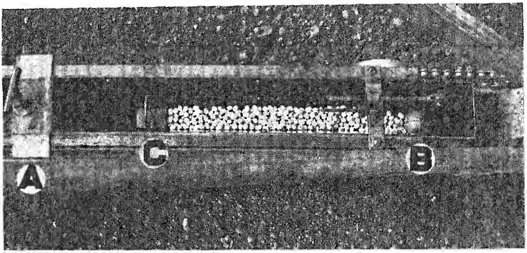

FIG. 2.—Seeding mechanism of nursery planter. A, adjustable gate; B, roller valve; C, seed stop.

The interchanging of sprocket wheels of available sizes permits planting of rows from 19 to 42 feet in length when the entire exposed 22-inch length of belt is utilized. Shorter rows may be planted by distributing the seed over a shorter length of the belt.

The planter was constructed by an Ames, Iowa, machinist at an approximate cost of $60.—MARTIN G. WEISS, *Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, Ames, Iowa.*

VITAMIN B_1 (THIAMIN CHLORIDE) AND THE YIELD OF CORN AND SORGHUM UNDER FIELD CONDITIONS[1]

THE work of Bonner and Greene[2] indicated that certain green plants may be limited in their growth by a deficiency of available vitamin B_1. These papers, together with the popular interest in the subject, led to the study of the influence of vitamin B_1 on the yields of corn and sorghum grown in the field at Manhattan, Kansas, in 1940. While recognizing the limitations of a single experiment, it is believed that a report of the results is appropriate.

The vitamin solution[3] was applied to two corn hybrids at two rates, i.e., 0.1 mg and 1.0 mg per hill. The hybrids were replicated five times in single-row plots each 10 hills long with hills spaced 42 inches apart. The treatment was applied at the rate of 0.1 mg per plant to duplicate plots of Blackhull kafir planted on each of two dates. The kafir plants

[1]Joint contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans. Contribution No. 319, Department of Agronomy.

[2]BONNER, J., and GREEN, J. Vitamin B_1 and the growth of green plants. Bot. Gaz., 100:226–237. 1938.

————, ————. Further experiments on the relation of vitamin B_1 to the growth of green plants. Bot. Gaz., 101:491–500. 1939.

[3]Chemical supplied by Merck and Company, Inc.

were spaced at 6-inch intervals in rows 20 feet long and 42 inches apart. The solutions were applied to the soil near the plants after thinning and about 2 weeks after planting. The slightly acid solutions were dropped from a pipette at the rate of 100 ml to each hill of corn and 10 ml to each kafir plant. Equal quantities of distilled water were added to the check plants. No subsequent applications were made. Chinch bugs destroyed the kafir of one planting date.

The yields of the two treated crops are shown in Tables 1 and 2. The vitamin B_1 treatment did not affect the yield of grain or stover of either crop significantly. No differences were observed in tillering, lodging, plant height, or maturity. These results are similar to those

TABLE 1.—*Grain and stover yields of corn hybrids treated with vitamin B_1.*

Kansas hybrid	Yield per acre							
	Grain, bu.				Stover, air-dry, tons			
	B_1 rate per hill				B_1 rate per hill			
	0.1 mg	1.0 mg	None	Av.	0.1 mg	1.0 mg	None	Av.
1104.......	34.0	36.5	33.3	34.6	1.83	1.96	1.94	1.91
1129.......	34.4	30.4	36.0	33.6	1.81	1.88	1.90	1.86
Average....	34.2	33.4	34.6	34.1	1.82	1.92	1.92	1.89

Source of variation	Analyses of variance			
	Grain		Fodder	
	D/F	Mean square	D/F	Mean square
Hybrids..........	1	1.95	1	0.43
Treatments........	2	0.98	2	1.14
Replications.......	4	2.24	4	0.39
Interaction:				
Hybrid × treatment	2	1.26	2	0.02
Error............	20	1.80	20	1.30

Mean squares for treatments and for hybrid × treatment were smaller than those for error.

TABLE 2.—*Grain and stover yields of Blackhull kafir treated with vitamin B_1.*

Treatment	Yield per acre					
	Grain, bu.			Stover, air-dry, tons		
	Plot A	Plot B	Average	Plot A	Plot B	Average
Vitamin B_1..........	49.7	36.7	43.2	4.74	4.12	4.21
Check.............	49.2	35.0	42.1	5.37	5.06	5.22

reported for other species of plants by several investigators.[4] Likewise, Bonner and Greene found that corn plants did not respond to added vitamin B_1.—H. E. MYERS, R. W. JUGENHEIMER, and E. G. HEYNE. *Kansas Agricultural Experiment Station, Manhattan, Kans.*

A SOIL BORER THAT PENETRATES DRY AND HARD CLAY SOIL

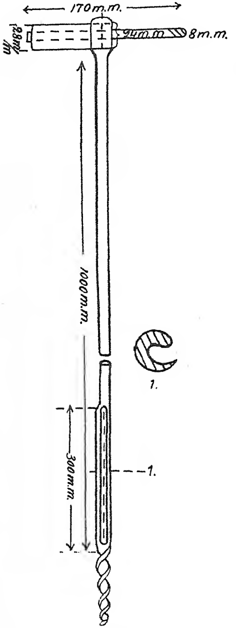

FIG. 1.—Diagram of borer, showing worm.

NEARLY 20 years ago the writer constructed the soil borer which has been described in several journals, e.g., Soil Science, 43:377–378. This borer has been used in soil mappings carried out by our Institute and has worked very satisfactorily. The borer has provided the soil surveyor with a little sample from the depth he wishes.

The only inconvenience with the borer has been that in spite of the long and sharp point the hardest clay soils, especially during the dry season, have been very difficult to penetrate.

Three years ago the problem was discussed with a Finnish blacksmith. He proposed to provide the point of the borer with a worm. This was done immediately and ever since the difficulties, even in driest soil, have disappeared.

The drawing in Fig. 1 shows the borer in its newest form. The handle is of wood with a steel support and the shaft a steel rod 12 mm thick. The one edge of the slot is drawn out a little and sharpened. If the worm in the point is of suitable form, the borer operates easily and rapidly.—ANTTI SALMINEN, *Soil Division, Central Agricultural Experiment Station, Helsinki, Finland.*

[4]ARNON, D. I. Vitamin B_1 in relation to the growth of green plants. Science, 92:264–266. 1940.

HAMMER, C. L. Effects of vitamin B_1 upon the development of some flowering plants. Bot. Gaz., 102:156–168. 1940.

HITCHCOCK, A. E., and ZIMMERMAN, P. W. Effects obtained with mixtures of root-inducing and other substances. Contr. Boyce Thompson Inst., 11:143–160. 1940.

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BOOK REVIEW

DRAINAGE AND FLOOD-CONTROL ENGINEERING

By George W. Pickels. New York: McGraw-Hill Book Co., Inc. Ed. 2. XII + 476 pages, illus. 1941.

THE original edition of this excellent textbook designed for courses in land reclamation was published in 1925. The purpose in the first edition was to place the whole subject of drainage, reclamation, and flood control on a basis more in keeping with advances in the sciences of hydrology, hydraulics, and soil physics. A great deal of work has been done in these fields during the past 15 years. The new edition aims to bring the subject up to date in the light of these new findings. This has resulted in the omission of some 95 pages of old material and the incorporation of 125 pages of new and revised material.

The agronomist and soil conservationist will find discussed such familiar subjects as precipitation, rainfall intensities, run-off, infiltration, detention, and storage. The drainage and conservation engineer will find a great deal of material on the engineering phases of the above subjects as well as stream measurements, flow, land drainage, pumping plants, and flood prevention through channel improvement, levees, reservoirs, etc. There is also a chapter on drainage law.

The volume contains a wealth of up-to-date information for anyone interested in the fundamentals underlying water movements and their management and control. (R.C.C.)

AGRONOMIC AFFAIRS

ORIGIN, AIMS, AND ORGANIZATION OF THE AMERICAN SOCIETY OF AGRONOMY

THE idea for the organization of the American Society of Agronomy apparently originated with the Agronomic Seminar of the U. S. Dept. of Agriculture. The committee appointed for the purpose of forming an American Society of Agronomy contacted workers in the field of agronomy throughout the United States during the fall of 1907. As a result of the activities of this committee and of state workers, a meeting was held in Chicago on December 31, 1907, at which time the American Society of Agronomy was organized.

The object of the Society is to increase and disseminate knowledge concerning soils and crops and the conditions affecting them. Membership is open to all individuals interested in these objectives. The objectives are carried out, first, through holding an annual meeting, and second, through the publication of the JOURNAL.

The Society continued along the lines of the original organization until November 18, 1936, when the members of the Society having specific interest in the field of soils and closely related work organized the Soil Science Society of America. This organization represented a merging of the American Soil Survey Association and the Soils Section of the American Society of Agronomy. The object of the new organization is to foster all phases of soil science and any person interested in the object of the Society is eligible for membership. The Soil Science Society also functions as the Soils Section of the American Society of Agronomy.

The Soil Science Society of America is organized in six fields in order to provide an opportunity for the consideration of specialized subjects. The six fields are Soil Physics; Soil Chemistry; Soil Microbiology; Soil Fertility; Soil Genesis, Morphology, and Cartography; and Soil Technology which includes Soil Conservation.

The Crops Section of the American Society of Agronomy is organized on the basis of subject matter. The divisions consist of Genetics, Cytology, Physiology, Taxonomy, Crop Production, Crop Improvement, Experimental Methods, and such others as may be deemed advisable. The program of the annual meetings frequently provides sections on extension and resident teaching.

The JOURNAL of the American Society of Agronomy publishes acceptable papers presented by the members of the Society to the editor throughout the year, and papers presented at the annual meetings which the author wishes to publish and which are accepted by the Editorial Committee. Throughout the years there has been a good balance between the number of articles published in the JOURNAL from each of the fields, soils and crops. The JOURNAL is recognized as the outstanding agronomy publication of the world. It has increased in size and importance with the growth of the Society. The first volume contained 238 pages and 39 papers, while Volume 32, 1940, contained 1,025 pages, 109 papers, 17 notes, 13 book reviews, and numerous reports of committees.

The papers presented at the meetings of the Soil Science Society of America are published in the PROCEEDINGS of that Society. Soils men who are members of the American Society of Agronomy are also privileged to submit papers for publication in the JOURNAL at any time.

The American Society of Agronomy which had a membership of only 101 at the time it was organized, had, at the time of the 1940 meetings, a total membership of 1,176 representing each state in the United States and 23 foreign countries.

R. I. THROCKMORTON, *Historian*.

THE THIRTY-FOURTH ANNUAL MEETING OF THE SOCIETY

THE thirty-fourth annual meeting of the American Society of Agronomy will be held at the Mayflower Hotel in Washington, D. C., November 12, 13, and 14. Tentative outlines for the programs for the Soils and Crops Sections are presented below.

PROGRAM FOR THE SOIL SCIENCE SOCIETY OF AMERICA

All Sections of the Soil Science Society plan to hold meetings and there will be some joint sessions of different Sections, particularly a symposium among Sections I, II, and V on "Soil Formation". Joint sessions between certain Sections of the Soil Science Society and the Crops Section of the American Society of Agronomy are also contemplated.

Those desiring to present papers before the Soil Science Society should communicate directly with the Chairman of the Section concerned and should also consult the "Program Instructions" which appear in Volume 5 of the PROCEEDINGS of the Soil Science Society and which will be available within the next few weeks. The Chairmen of the different Sections of the Soil Science Society are as follows:

Section I—Soil Physics, Willard Gardner, Utah State College, Logan, Utah.

Section II—Soil Chemistry, C. E. Marshall, University of Missouri, Columbia, Mo.

Section III—Soil Microbiology, O. H. Sears, University of Illinois, Urbana, Ill.

Section IV—Soil Fertility, J. A. Naftel, Alabama Polytechnic Institute, Auburn, Ala.

Section V—Soil Genesis, Morphology, and Cartography, H. H. Krusekopf, University of Missouri, Columbia, Mo.

Section VI—Soil Technology, G. D. Scarseth, Purdue University, Lafayette, Ind.

The general program of the Soil Science Society will be devoted to a discussion of calcium, with three speakers who will deal with the physio-chemical relationships, the biological relationships, and the geographic relationships. The banquet speaker will be Dr. Bushrod W. Allin who will discuss the contributions of soil scientists to agricultural planning.

PROGRAM FOR THE CROPS SECTION

Preliminary plans for the meeting of the Crops Section of the Society are announced by the Chairman, Professor C. J. Willard, Ohio State University, Columbus, Ohio. Several sessions are being held open for contributed papers. Brief papers presenting the results of current research or of taking research to the farmer, are especially desirable. Those wishing to present papers are requested to send the title to the Chairman of the Section before August 1. An abstract of the proposed paper of not over 200 words must be submitted either with the title, or before August 15.

Other sessions of the Crops Section now planned include a symposium on grass silage, Dr. T. E. Odland, Chairman; a symposium on teaching farm crops, Dr. L. F. Graber, Chairman; a session on the breeding of grasses, Dr. G. W. Burton, Chairman; a symposium on corn improvement, Dr. G. F. Sprague, Chairman; a symposium on crop-weather relations, Dr. H. H. Laude, Chairman; and several others.

An exhibit of methods and apparatus which have been found to save time or give better results is being arranged by Dr. G. W. Burton. A trip to the research center at Beltsville is planned for one afternoon.

SUMMER MEETING OF CORN BELT SECTION

THE summer meeting of the Corn Belt Section of the Society will be held at the Purdue University Agricultural Experiment Station, Lafayette, Indiana, June 19 to 21, inclusive. Following registration and a brief morning program on Thursday, June 19, the various special interest groups will be organized to inspect the work on the soils and crops experiment farm, the pasture experiments on the dairy farm, and the hydrologic studies on the Throckmorton Farm.

The wheat breeders and the soil fertility section will have special indoor sessions on Friday afternoon, while the soil surveyors will have special field trips. On Saturday morning there will be trips to outlying experiment fields.

The Corn Belt Grassland Conference will be held at Purdue on Tuesday and Wednesday, June 17 and 18.

MEETING OF WESTERN SECTION

THE Western Section of the American Society of Agronomy will meet at Corvallis, Oregon, June 12 to 14, inclusive. The program will be a combination of formal papers and group discussions on selected topics.

The President of the Section is Professor A. H. Post of the Montana State College and the Secretary is Professor D. D. Hill of the Oregon State College.

JOURNAL

OF THE

American Society of Agronomy

VOL. 33 JUNE, 1941 No. 6

THE EFFECT OF ROOT PRUNING AND THE PREVENTION OF FRUITING ON THE GROWTH OF ROOTS AND STALKS OF MAIZE[1]

J. T. SPENCER[2]

PREVIOUS observations of the writer[3] indicated apparent wide differences in the growth of lateral or secondary roots among various strains of inbred and hybrid corn. It was found in these studies that the main or primary roots frequently were severely damaged by insects, particularly by the larvae of the southern corn rootworm, *Diabrotica duodecimpunctata* Oliv. When a main root was completely severed by larvae, an increased growth of lateral roots occurred in most strains of corn.

The present paper reports the results of experiments to determine the effects of (1) root pruning and (2) bagging ear shoots to prevent pollination and fruiting upon the growth of roots and stalks of inbred and single-crossed strains of corn. Sayre, Morris, and Richey[4] found that the prevention of fruiting in corn resulted in an increased accumulation of total sugars in the stalk.

MATERIAL AND METHODS

The inbred lines, Ohio 51, 84, 56, 65, and 02, Indiana WF9, U. S. 4-8, and all the possible 21 single-cross hybrids among them were selected for the study. The planting arrangement consisted of three random replications of one-row plots. Each row contained 30 plants spaced at 10-inch intervals. Untreated plants alternated with those subjected to a given treatment.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Agronomy Department, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication February 12, 1941.

[2]Assistant in Agronomy, Kentucky Agricultural Experiment Station, Lexington, Ky.; formerly Agent, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

The writer gratefully acknowledges the assistance of G. H. Stringfield and J. D. Sayre of the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Ohio Agricultural Experiment Station.

[3]SPENCER, J. T. Root studies of some inbred lines and hybrids of maize. Abstracts of Doctoral Dissertations, No. 29: 239–251. The Ohio State University Press. 1939.

[4]SAYRE, J. D., MORRIS, V. H., and RICHEY, F. D. The effect of preventing fruiting and of reducing the leaf area on the accumulation of sugars in the corn stem. Jour. Amer. Soc. Agron., 23:751–753. 1931.

The corn was planted on Wooster silt loam at Wooster, Ohio, on May 13, 1938. Fifty-five days later, when main roots had appeared at approximately five nodes, the roots of part of the plants were pruned by forcing a 4½-inch florist's spade down 7½ inches into the soil at a distance of 2 inches from the stalk. The first pruning was confined to one side of the plant, but a week later a second root-pruning was performed on another side, and 2 weeks later a final pruning was made on a third side.

Fruiting was prevented by placing small glassine bags over the ear shoots before the silks appeared and, as soon as feasible, replacing the small bags with 12-pound kraft bags.

The above-ground portions of the plants were harvested on September 26. Green weights were recorded for the entire stalk, and, after drying, weights of stover and ears were obtained.

On September 29 and 30 the force required to pull up the stubs was determined with a special pulling machine equipped with a spring scale, a single movable pulley, and a clamp for grasping the stalk. After approximately 300 stalks from each of the three treatments and the check had been pulled, the roots were soaked in a large tank of water. The soil then was carefully washed from the roots with a fine spray of water from a garden hose. Care was taken to avoid damage to the lateral roots in so far as possible. Upon completion of the washing, the roots remained in water for a few hours until measured and then were placed in a drying room. Dry weights of both main and lateral roots were determined.

EXPERIMENTAL RESULTS

Differences in the relative abundance of the lateral roots were especially pronounced. Plants which had been prevented from fruiting had particularly dense root systems resulting from the prolific growth of lateral roots (Fig. 1). The roots of plants receiving this treatment were much whiter and fresher than those of untreated plants. Also the stalks at harvest retained a brighter green color and were more succulent than were the untreated stalks.

The stimulated lateral root growth resulting from severance of the main roots and the prevention of fruiting is shown in Fig. 1.

PULLING RESISTANCE

The effects of the three treatments on the resistance offered by the roots of inbred lines and single crosses, to a direct vertical pull are shown graphically in Figs. 2 and 3. The performances of the single crosses of the individual lines are shown as averages of all the six possible single crosses in which each line occurred. Thus the data for line 56 are represented in the columns above "56 ×" and include the average results for the following single crosses: 56 × 51, 56 × WF9, 56 × 65, 56 × 84, 56 × 02, and 56 × 4–8.

The zero point in Figs. 2 and 3 is the mean pulling resistance of the untreated plants of the indicated line. The inbred lines (Fig. 2) showed remarkable differences in response to the treatments. As a result of root pruning, six of the inbred lines showed a lower pulling resistance, and one, inbred line 56, had a slightly higher pulling resistance than the untreated plants. The latter difference probably was too small to be significant. The decreases in pulling resistance among the six in-

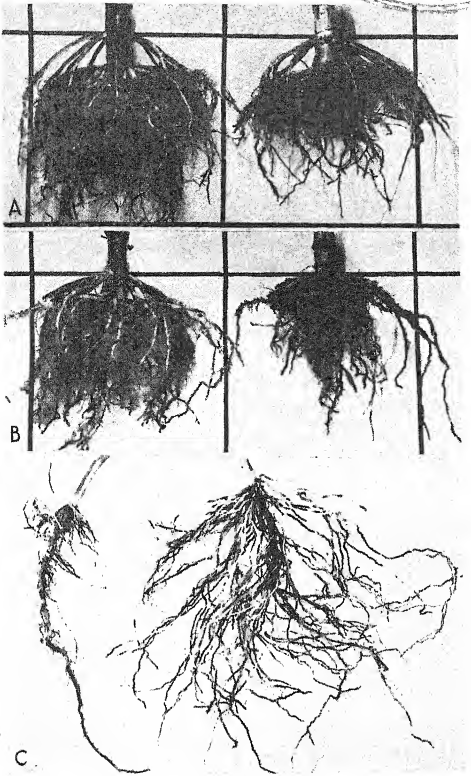

FIG. 1.—Corn roots of the single cross 84 × 4–8, showing the effects of treatment. A, left, plant prevented from fruiting and, right, untreated plant. B, left, plant subjected to both root pruning and the prevention of fruiting and, right, plant subjected only to root pruning. C, two main roots from a plant subjected to root pruning and prevented from fruiting. Left, unsevered; right, severed root showing increased development of lateral roots.

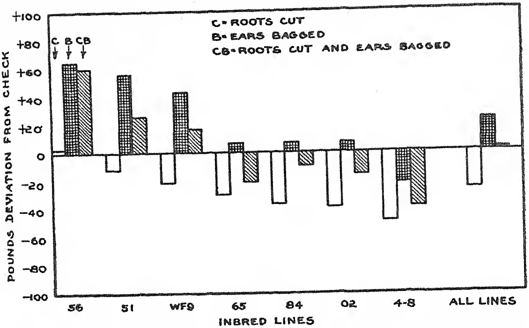

FIG. 2.—Effect of treatment upon the pulling resistance of seven inbred lines of corn compared with untreated plants of the same inbred lines.

bred lines ranged from 12 to 49 pounds, or 12 to 46%, and averaged 26 pounds, or 19%, for all seven inbred lines.

The prevention of fruiting increased the pulling resistance of six of the seven inbred lines. The increases in these six ranged from 7 to 65 pounds, or 4 to 56%, and the average increase for all inbred lines was 23 pounds, or 17%.

The responses of the inbred lines to root pruning and to the prevention of fruiting were associated to some extent. Fig. 2 shows that inbred lines 56, 51, and WF9, the strains which showed the greatest

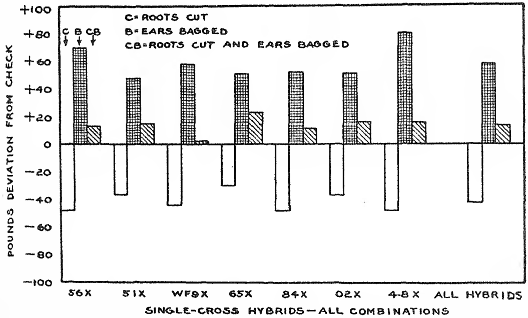

FIG. 3.—The effect of treatment upon the pulling resistance of the single crosses of seven inbred lines compared with untreated plants of the same hybrids.

increases in pulling resistance as a result of "bagging", also had the least reduction in pulling resistance as a result of root pruning. The deviation in pulling resistance of the "cut-bagged" plants, which received both treatments, from the untreated checks, seems to be approximately equal to the algebraic sum of the deviations of the "cut" and the "bagged" plants.

The single crosses are arranged by parent lines in the same order in Fig. 3 as were the inbred lines in Fig. 2. The responses shown by the inbred lines are not in the same order in the two groups, and the hybrids were less variable in their responses. All the hybrids lost in pulling resistance as a consequence of the root pruning, and all gained in pulling resistance as a result of the prevention of fruiting, either alone or in combination with root pruning. The reduction in pulling resistance among the hybrids ranged from 30 to 48 pounds, or 13 to 21%, as a result of root pruning. The prevention of fruiting caused a gain of 48 to 70 pounds, or 19 to 34%, in pulling resistance. The hybrids 56×, 4-8×, and 84×, which showed the greatest reduction in pulling resistance after root pruning, also gained the most in pulling resistance as a result of the prevention of fruiting (Table 1). This relationship did not occur in the inbred lines.

TABLE 1.—*Effect of various treatments on the percentage of total, main, and lateral roots and the pulling resistance of single-cross hybrids.*

Common inbred parent*	Pounds of pulling resistance gained or lost			Percentage of lateral roots gained			Percentage of main roots gained or lost			Percentage of total root weight gained or lost		
	C†	B†	CB†	C	B	CB	C	B	CB	C	B	CB
56×..........	−48	+70	+13	+42	+ 83	+143	− 7	+38	+22	+ 4	+53	+55
4-8×..........	−48	+80	+16	+ 9	+ 90	+126	− 6	+42	+40	− 3	+60	+55
84×..........	−48	+52	+11	+18	+ 69	+134	−14	+37	+31	− 9	+42	+48
51×..........	−37	+48	+15	+67	+104	+170	− 1	+52	+38	+10	+52	+60
WF9×.........	−44	+58	+ 2	+17	+ 75	+107	−11	+33	+20	− 5	+42	+38
02×..........	−37	+51	+16	+ 5	+ 92	+120	−12	+44	+28	− 9	+45	+36
65×..........	−30	+51	+23	+40	+ 52	+109	− 6	+40	+33	+ 5	+45	+53

*Mean of six single crosses with the common parent indicated. Approximately 60 root systems are included in each mean.

†C = plants with roots pruned; B = plants bagged to prevent fruiting; CB = plants with roots pruned and also bagged to prevent fruiting.

ROOT RECOVERY

Further studies were made to determine the causes for the very pronounced effects of root pruning and the prevention of fruiting upon pulling resistance.

The pruning of a well-developed main root stops its further elongation, and the weight of a main root is reduced about in proportion to the amount that has been severed. Increases in the weight of main roots after being severed, therefore, must come from radial growth, if any, or from the growth of new main roots. As is shown here, recovery of corn roots after pruning consists largely in the growth of lateral roots from the stubs of the severed roots.

Fig. 4 shows the weight in grams (moisture-free basis) of the roots of the treated and untreated hybrid plants. The pruning treatment reduced the average weight of main roots 8% and increased the weight of the lateral roots 28%. Root pruning resulted in a slightly decreased total root weight in four groups of hybrids and a slightly increased total root weight in the remaining three groups. An average for all the hybrids showed a decrease in total root weight of only 1%. The slight difference shows the ability of corn roots to recover from damage by certain insect larvae. The striking growth of lateral roots after the main roots were pruned is shown in Fig. 1, C.

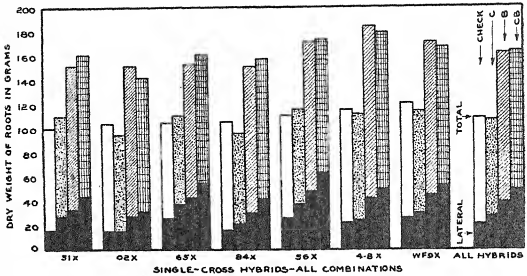

FIG. 4.—The effect of treatment upon the dry weights of the total, main, and lateral roots of seven groups of single-cross hybrids. "C" denotes roots pruned, "B" the prevention of fruiting, and "CB" a combination of these two treatments.

The increased growth of lateral roots following root pruning did not increase the pulling resistance appreciably (Table 1). Thus, two single-cross groups (51 × and 02 ×) each showed losses of 37 pounds in pulling resistance following root pruning despite increases in lateral roots of 67% and 5%, respectively.

The prevention of fruiting by bagging the ear shoot before the emergence of the silks resulted in all instances in a much greater total dry weight of roots (Fig. 4). The average increase was 27% for the inbred lines and 48% for the hybrids. The main roots increased 41% in average dry weight and the lateral roots 82%. The various single crosses differed considerably in their response to treatment, as is evidenced by increases in main roots of 33 to 52% and in lateral roots of 62 to 104%. The stimulation to root growth resulting from the prevention of fruiting was readily observable (Fig. 1), and 25% more force was required to pull up the treated plants.

Four of the seven groups of single crosses showed slightly greater total root weights after the combined treatment of prevention of fruiting and root pruning than they did after the former treatment alone (Fig. 4). The other groups showed slight reductions in total root weight. As shown in Table 1, the main roots from the plants

given the combined treatment were 11% lower in dry weight than those from the plants given the bagging treatment alone, but they showed an average gain of 30% in dry weight in comparison with the untreated plants. The average increase in lateral root weight amounted to 130% for all the hybrids; the increases ranging from 107 to 170%.

PERCENTAGE OF LATERAL ROOTS

Since the percentage of lateral roots as compared with total dry weight of roots was greatly modified by treatment, the data on this

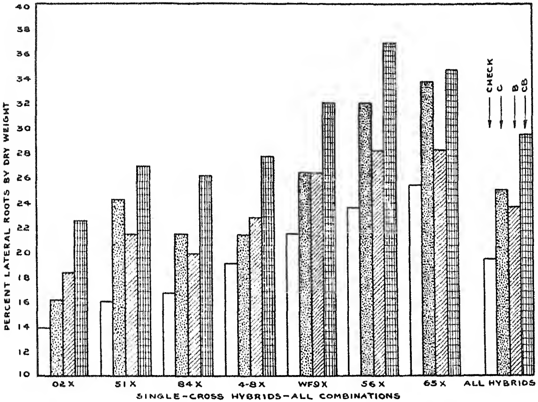

FIG. 5.—The percentage of lateral roots, by dry weight, in the total root system of treated and untreated plants in seven groups of single-cross hybrids. "C" denotes root pruned, "B" the prevention of fruiting, and "CB" a combination of these two treatments.

point are summarized graphically in Fig 5. In every instance, the untreated plants exhibited the smallest proportion of lateral roots in the total root system. The lateral roots averaged 19.5% in the untreated group and 25.1% when the root systems were pruned. The prevention of fruiting always increased the percentage of lateral roots; but the relative responses for the two treatments were not uniform for all the hybrids. The combined treatments gave the highest percentage of lateral roots in every group of hybrids, an average of 30% and a range of 23 to 37%.

WEIGHT OF GRAIN AND STOVER

The weights of the above-ground parts of the corn plants are summarized in Fig. 6 and Table 2. The effects on top growth are nearly

opposite those on the root growth. Root pruning, the prevention of fruiting, and the combined treatments decreased the weights of the above-ground parts of the plant in the order enumerated. In the two treatments which included the prevention of fruiting, a considerable

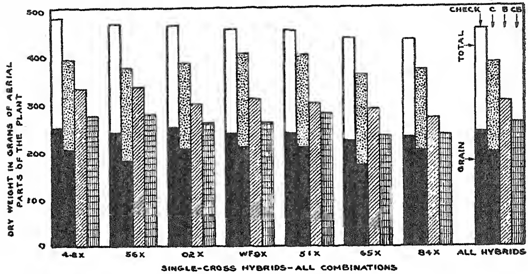

FIG. 6.—The effect of treatment upon the dry weights of the above-ground parts of the corn plant in seven groups of single-cross hybrids. "C" denotes roots pruned, "B" the prevention of fruiting, and "CB" a combination of these two treatments.

TABLE 2.—*Effect of various treatments on the dry weights of the above-ground parts of the single-cross hybrids.*

Common inbred parent*	Percentage of total weight lost			Percentage of stover weight gained or lost			Percentage of grain weight lost	Ratio of grain weight to stover weight	
	C†	B†	CB†	C	B	CB	C	Untreated	C
56X	-20	-28	-41	-13	+48	+23	-26	1.07	0.91
4-8X	-18	-31	-43	-18	+44	+19	-18	1.07	1.07
84X	-15	-38	-46	-18	+32	+15	-12	1.12	1.20
51X	-11	-33	-38	- 9	+41	+31	-13	1.11	1.07
WF9X	-12	-32	-43	-11	+42	+20	-12	1.08	1.08
02X	-17	-36	-44	-16	+40	+20	-19	1.17	1.13
65X	-18	-34	-47	-13	+34	+ 8	-23	1.03	0.90

*Each horizontal group represents the mean of six single crosses with the common parent indicated. Approximately 60 plants are represented by each mean.
†C = plants with roots pruned; B = plants bagged to prevent fruiting; CB = plants with roots pruned and also bagged to prevent fruiting.

drop in total weight of top growth was expected because grain development was prevented. However, prevention of fruiting resulted in increases in the weights of stover averaging 40% following the prevention of fruiting alone and 19% following the combined treatment.

The treatments produced the following average reductions in the total dry weight of the above-ground parts: Root pruning, 16%; the prevention of fruiting, 33%; the combination treatment, 43% (Table 2).

The average losses resulting from the root pruning were 18% in grain weight and 14% in stover weight. It would thus appear that the pruning treatment had a more deleterious effect upon grain weight than upon stover weight.

The average ratio of grain to stover was 1.09 for the untreated plants and 1.05 for the root-pruned plants.

SUMMARY

The effects upon subsequent growth of root pruning, the prevention of fruiting, and a combination of these treatments were studied in 7 inbred lines of corn and the 21 possible single crosses among them.

The roots of both inbreds and hybrids showed marked reductions in pulling resistance at maturity as a result of the root pruning. On the hybrids, root pruning always resulted in a decreased weight of main roots and an increased weight of lateral roots.

As a result of the prevention of fruiting, the roots of hybrid plants increased 48% in total dry weight and 25% in pulling resistance in comparison with untreated plants. The combination treatment of root pruning and the prevention of fruiting likewise resulted in increases in pulling resistance and root dry weights.

The response to the treatments consisted largely in increased development of lateral roots. In comparison with the check plants, the treatments gave the following average increases in lateral roots: Root pruning, 28%; the prevention of fruiting, 82%; and the combination of these two treatments, 130%.

Root pruning resulted in an 18% reduction in grain weight and a 14% reduction in stover weight. This treatment also reduced the grain-stover ratio of four of the seven groups of hybrids.

OBJECTIVES IN BREEDING FOR IMPROVED QUALITY IN HARD WHEAT[1]

W. F. GEDDES[2]

IN the early years of purposeful plant breeding the primary aim was the development of high-yielding varieties and it was not until after a general world trade in wheat had been established that the industrial quality of the grain became a factor of importance in determining the profits of the producer. In fact, it was not until after the wide-spread adoption of the roller milling process in the United States in the late 1870's that hard wheats came to be favorably regarded. Wheat breeders seeking to develop suitable varieties for the Great Plains area then began to pay more attention to the development of vitreous high-quality types of spring and winter wheats. The importance of considering industrial quality became greater as the milling industry passed from local custom milling to large efficient centralized organizations and also with the trend towards the concentration of baking in large plants. The increase in the number of large mechanized bakeries which gradually established scientific control made it necessary for the miller to pay more and more attention to uniformity and quality in wheat. These requirements were reflected in premiums for certain types of wheat and it became necessary for plant breeders to consider quality, as well as yield and other desirable characters, in their wheat-breeding programs.

During the closing years of the last and the early part of the present century, the more progressive experiment stations in important wheat-growing regions installed experimental testing equipment as an aid to plant breeders in selecting those varieties and strains which possessed desirable baking characteristics. Examples of the early application of milling and baking tests to plant breeders' material may be found in the reports of Hays and Boss (9),[3] Guthrie (7), Harcourt (8), and Saunders and Shutt (19). The experimental milling and baking equipment described by Saunders and Shutt undoubtedly played a significant part in the development of Marquis wheat by the late Sir Chas. E. Saunders—a hard red spring wheat which was commercially established in 1911 and rapidly became the standard of quality on the world's markets for bread wheat. Since these early studies, the science of cereal chemistry has advanced rapidly and an increasing measure of scientific control must be exercised by the millers in producing flour which will meet the rigid and highly specialized requirements of the baking trade. The difficulties of the hard wheat breeders are increased by the necessity of developing high-yielding wheats which will not only resist or escape as many cultural hazards as possible but will also meet the exacting and complex re-

[1]Contributed from Division of Agricultural Biochemistry, University of Minnesota, St. Paul, Minn. Paper No. 1887, Scientific Journal Series, Minnesota Agricultural Experiment Station, also presented at the annual meeting of the Society held in Chicago, Ill., December 4 to 6, 1940. Received for publication on February 15, 1941.

[2]Professor of Agricultural Biochemistry.

[3]Figures in parenthesis refer to "Literature Cited", p. 502.

quirements of the milling and baking trades. Today, no reputable wheat breeder would consider releasing a new variety without exhaustive milling and baking tests; in short, the combined skills and technics of the geneticist and the cereal chemist are required to bring any wheat-breeding program to a successful outcome.

VARIOUS ASPECTS OF WHEAT QUALITY

In discussing the objectives in breeding for improved quality in bread wheats it is first necessary to define the implications of the term quality. This is extremely difficult as it is impossible to state in quantitative terms or with any degree of verbal precision the various component factors of wheat quality. Fisher (2) has pointed out that the wheat grower, the miller, the baker, and the bread consumer are concerned with different aspects of the problem of wheat and flour quality and that these are not necessarily identical. Thus, to the farmer, quality is primarily associated with the factors affecting yield and grade; to the miller, quality in the restricted and technical sense is associated with flour yield and the ease of milling; to the baker, quality in the restricted sense implies bread yield and the ease of processing; finally, the consumer values the bread according to its quality alone. In actual practice, however, Fisher points out that these restrictions as to the different meanings of the term quality cannot be strictly applied. The baker must take into consideration the demands of the bread consumer and the miller in turn must supply the baker with flour of appropriate characteristics, so that in the wider sense good milling quality must include good baking quality. While the wheat grower's responsibility seems to end when he sells his wheat, the miller's responsibility only begins when he sells his flour, since if it fails to give satisfaction he must make good its defects or lose his trade.

It is therefore not surprising that the milling industry is deeply concerned in the work of wheat breeders and, as pointed out by Sherwood (20) and Swanson and Kroeker (23), is apt to be critical of new varieties. The milling trade is reasonably well satisfied with the best varieties under cultivation and in the past some new varieties have been introduced which have not been entirely acceptable. Sherwood has stated that millers are prone to expect more ideal characteristics than those of existing varieties and Swanson and Kroeker have pointed out that wheat breeders may expect objections to their new creations if they are measurably different from the old. If those interested in wheat improvement would carefully scrutinize the needs of the trade, the progress already made shows that, although difficult, it is possible to produce new varieties, e.g., Thatcher, which will reduce the losses of wheat producers and which at the same time will be satisfactory to the trade.

QUALITY FACTORS RELATED TO GRADING

The official grade is an important factor in determining the return to the grower and it is desirable in his interests that a variety should

grade well but, in the interests of the miller, the physical properties included in determining the grade should reflect the utility value of the wheat.

In early hybrid generations, certain physical properties, such as texture and plumpness, are the only criteria of quality which can be readily applied by the plant breeder and it would therefore be expected that these physical properties of a new variety would be satisfactory. It is sometimes necessary to sacrifice appearance for other desirable characters and there are several examples of existing varieties in which the appearance of the grain is deceptive.

In some cases, the shape of the kernel and its physical characteristics cause a variety to be placed in a wheat class which is not justified by its actual performance. Kawvale, for example, is graded as a soft winter wheat, yet it produces a granular flour of unsatisfactory characteristics for cake baking. From its utility value it would be more correctly classified as a hard wheat. For efficient inspection and grading, the kernel characteristics of wheat should correspond to those of the class of wheat in which it should be placed from the standpoint of utility value.

It is the writer's experience that the grading factors are much more reliable indices of milling and baking quality within varieties than they are considering all varieties. Many of the difficulties connected with grain grading are directly associated with the increase in the number of varieties. When the bulk of the wheat reaching the markets was of one variety, environmental conditions (including plant diseases) were virtually the only factors affecting physical appearance and the relative test weight and vitreousness of the samples were fair indications of intrinsic value. When we have inherent differences between varieties and differential reaction to environment superimposed on the general effect of environmental conditions, test weight and kernel texture are much less reliable indices of milling and baking value.

Apart from moisture content, flour yield, as pointed out by Fisher and Jones (3), depends upon the shape, size, and density of the kernel, thickness of bran coat, and size of germ, but, as far as the writer is aware, no detailed studies have been made of the way in which these variables influence the relation between test weight and flour yield. It is well known, however, that certain varieties give flour yields which are out of line with those which would be anticipated from their test weights. The most outstanding example among spring wheats is Nordhougen, which is characterized by a relatively low test weight yet gives phenomenally high flour yields.

Vitreousness is used as a grading factor because of its relation to protein content and hence indirectly to baking strength. This kernel characteristic may, however, be very misleading. An outstanding example is the Canadian variety Garnet—an early-maturing hard red spring wheat which has caused serious difficulties in grading and marketing. This variety is characterized by excellent appearance, remaining hard and vitreous at approximately 2% lower protein content than Marquis; moreover, baking tests have shown that, at equivalent protein levels, Garnet is lower in strength than Marquis thus

accentuating the "discrepancy" between vitreousness and baking strength.

The case of Garnet wheat represents one where the appearance is better than the performance, which is to the benefit of the producers, for a time at least, but there are examples where the actual quality is superior to that indicated by the appearance. Thatcher wheat is rather unprepossessing in appearance, the kernel being relatively small, and tending to be dull and pale especially if slightly weathered. Yet the milling and baking quality of this variety has been acceptable to the United States, Canadian, and European trade, although in view of its poor appearance it was necessary for the Canadian Government to acquaint overseas buyers with the desirable properties of this wheat a year in advance of its bulk shipments by sending large trial shipments to leading millers in England and Scotland.

In many sample markets, a protein certificate supplements the grade certificate as an aid in the market evaluation of wheat. This practice is justified by numerous researches. Larmour (13), Geddes and Aitken (4), and McCalla (18) have shown that the loaf volume of hard red spring wheat flours is a linear function of wheat or flour protein content, providing a suitable baking method is used, and Larmour, Working, and Ofelt (16) have reported a similar relationship with hard winter wheats. Indeed, of the various physical, physico-chemical, and chemical properties of wheat, flour, and dough which have been investigated as possible measures of baking strength, protein content has shown the highest correlations. Certain varieties, however, such as Garnet (Larmour, 13; McCalla, 18) and Chiefkan (Larmour, Working, and Ofelt, 16), fail to exhibit the strength one would expect from the general regression of loaf volume on protein content for the class of wheat in question. This is a reflection of differences in gluten characteristics.

It would obviously improve the efficiency of the grading system and simplify the market evaluation of wheat if the physical appearance and protein content of all varieties uniformly reflected their intrinsic value, although this is an ideal which probably never can be attained.

FACTORS INVOLVED IN MILLING QUALITY

The milling quality of hard wheat, using the term to refer only to milling characteristics, is associated primarily with high flour yield and ease of milling. The kernels should be plump and uniformly large in size to permit ready separation of foreign material without loss of millable wheat. The wheat should absorb water readily and uniformily in the tempering process and produce a high yield of flour with a maximum and clean separation from the bran and germ without undue consumption of power.

Because of the close relationship between the degree of refinement and the ash content of flour milled from any particular lot of wheat, bakers frequently specify the maximum ash content in their flour contracts, very fine distinctions often being made. Careful studies by Sherwood and Bailey (21) have shown that the ash content of any particular flour grade increases with the ash content of the wheat

from which it is milled and hence ash is not an absolute indication of grade in the instance of flours milled from different wheats. If a miller is forced to meet a certain maximum ash limit, his only alternative in milling high-ash wheat is to include less of the lower grade streams, thus producing a shorter patent. Such an adjustment increases milling costs and consequently a new variety should have at least as low an ash content as accepted varieties. (The hard red winter wheat variety Iobred is said to produce flour of unusually low ash content.)

This brief consideration of the desirable characteristics of a variety in relation to milling would not be complete without reference to flour bleaching, flour maturing, and flour diastating. The flour should be of low yellow pigment content. The pigments present should be susceptible to bleaching with the common bleaching and maturing agents employed and produce a flour of satisfactory color (creamy, not grey) with the miminum of cost for reagents and without injury to baking quality.

In recent years it has become clear that many baking failures can be traced to insufficient gas production under the particular baking conditions employed and it is now the common practice of mills to maintain a definite level of "gassing power" in their flours. When necessary to increase this factor, the miller normally adds a small percentage of malted wheat flour. As this is an added expense, it is preferable that sound wheat of the new variety should produce flours which require relatively little correction for this factor. However, flour gassing power need not be regarded as an essential quality factor since adjustments can be so readily made.

The experimental determination of milling quality on plant breeders' samples leaves much to be desired. In view of the limited material available, single tests employing only from approximately 1,000 to 2,000 grams of wheat are usually conducted on batch-type mills in which the various stocks are transferred manually. In general, all samples are tempered for a fixed time to a definite moisture content. With such small samples it is impractical to vary the adjustment of the rolls during any given operation and the entire process is perforce conducted in a rather stereotyped manner. While major differences in milling characteristics may be detected, it is the opinion of many cereal technologists that variations in tempering requirements or the ease of milling which may show up in a different distribution of the stocks in a large continuous flow mill may remain undetected in experimental milling. Consequently, in tests conducted on rod-row material, little precise information is obtained on tempering requirements, ease of milling, or flour-yielding ability. In recent years semi-commercial tests employing 60 bushels or more of wheat have been used in testing material grown in increase plots, thereby providing more adequate information regarding the milling properties of the new varieties.

FACTORS ASSOCIATED WITH GOOD BAKING QUALITY

The terms "baking quality" and flour "strength" have been used with many different meanings. In this paper, "baking quality" is

used to designate, in a general way, those characteristics of a flour which make it desirable for bread-making purposes, whereas "strength" refers to the inherent capabilities of the flour to produce good bread under conditions of adequate gas production. Humphries (10) has defined baking quality as "the sum of excellence on several points." Fisher (2) has emphasized that good baking quality is a relative term and must be judged from the point of view of the use to which the flour is put and the method of use. Flour is baked under widely varying conditions with regard to baking formulas, extent of mixing, and fermentation; also, the character of the loaf desired differs according to locality.

In general, however, a flour for bread-making purposes should have fairly high water absorption and produce doughs of satisfactory handling properties which will yield bread of the volume, break, shred, crust color and crumb grain, texture, and color desired by the baker over a considerable range of mixing and fermentation conditions. In other words, baking quality involves more than the production of satisfactory bread over a considerable range of baking conditions; it also includes the facility with which large masses of dough can be handled in the bakery and the yield of bread obtainable.

Commercially, the strength and baking characteristics of a flour must be selected to meet particular baking conditions. This can be best elaborated by considering the general characteristics of U. S. flours for the family trade, and for commercial shops making "pan" and "hearth" baked bread, respectively. The general strength of the flour for these three classes of trade must be increased in the order named. In home baking, the whole procedure involves rather mild treatment, hand or very slow speed machine mixing, and gentle fermentation, so that best results are obtained with a flour of lower protein content and more easily conditioned gluten than would be satisfactory for commercial bakeries.

For the manufacture of pan bread, a medium strong flour is required to withstand high-speed mixing and produce a dough possessing the physical characteristics which will permit machine manipulation without difficulty. For hearth baking a flour of still higher protein content which yields a "tough" dough is required in order to secure the necessary "stability," that is a dough which will resist flattening under its own weight.

The varying requirements of the baking trade have been clearly emphasized by Kent-Jones (11) and Larmour (15) and greatly complicate the problem of test baking. From the standpoint of the miller and baker, baking quality is measured in terms of the suitability of the material for a particular baking schedule and hence the standards are not constant and preference plays a large part in the final appraisal. Geddes and Larmour (6) have pointed out that commercial flour testing resolves itself into determining the suitability of the flour for specific bakeship conditions which are more or less definitely known. In testing wheat quality an effort must be made to measure not only the "strength" or the inherent potentialities but also the baking characteristics since the raw material may be submitted to a wide range of treatment in commercial milling and baking practices.

While it is not the purpose of this paper to deal with testing methods, it is desirable to mention that in testing wheat varieties the flours are experimentally milled and usually baked without bleaching treatment and little or no natural aging. Also, the "gassing power" of experimentally milled flours is much lower than that of flours commercially milled from the same wheat. As the gluten of untreated, unaged flours appears more resistant to fermentation, it is necessary in determining strength to modify the baking formulas normally used in commercial flour testing.

Baking tests using different formulas and procedures are employed which, under ideal conditions, are designed to reveal not only the inherent strength of the sample, but also to secure a measure of the baking conditions, such as extent of mixing, length of fermentation, and oxidation requirements necessary to obtain the optimum loaf. These experimental baking tests can only be adequately interpreted in terms of commercial suitability of the variety by comparison with similar studies with a variety or varieties of established commercial value grown under the same environmental conditions.

In this country, the characteristics of the finished loaf, particularly loaf volume, are generally the chief criteria of strength, whereas in England and many European countries, the physical properties of the fermenting dough, as judged by the subjective impressions which the baker gets when making the dough, constitute the main and in some cases the only measure. This difference in method of evaluating strength is not surprising when it is recalled that flours milled from the soft low-protein wheats grown in insular climates yield "soft" sticky doughs which are not suitable for machine processing and which "flatten out" when allowed to stand on the bench or are baked on the hearth. Accordingly, in Europe greater emphasis is placed on dough properties than on loaf volume-producing ability and this must be taken into consideration in evaluating varieties for export purposes.

It cannot be assumed that with individual varieties desirable handling properties and strength, as measured by loaf volume, go hand in hand. That the evaluation of strength by these two criteria will give different relative placings of a series of flours was indicated in a study by Kent-Jones and Geddes (12) but has now been quite definitely established as the result of extensive (unpublished) tests in America and abroad of a new hard spring wheat hybrid developed in Canada. In rod-row tests this hybrid, which we will designate as A, was found to be consistently the highest in baking strength, as measured by loaf volume with various procedures, of all the new hybrids and standard varieties under study. It was then grown in increase plots and submitted to extensive collaborative testing by 21 Canadian, United States, and overseas chemists in comparison with Thatcher and certain other promising hybrids. In general, 14 American cereal chemists placed this particular hybrid as the most desirable of the group, while the European collaborators were virtually unanimous in placing it at the bottom of the list. In the instance of another hybrid later released as Regent, the relative placing by the two groups of workers was much more consistent. Commercial milling and baking

tests conducted in England the following year showed that hybrid A was unsuitable for use as a strong wheat for blending purposes. While the finished bread was perfectly satisfactory, this variety gave a softer type of dough and had somewhat different fermentation requirements than wheats of the Marquis type. As one English cereal chemist expressed it, hybrid A would be an excellent hard red winter wheat. In these tests, the hybrid subsequently released as Regent showed a better "balance" between dough properties and loaf volume—producing ability and for the overseas trade at least was preferable to hybrid A.

The estimation of baking quality largely on the basis of empirical observations of the handling properties of the dough during fermentation does not provide permanent quantitative data and in recent years there has been a great deal of interest in the development of mechanical devices for measuring and recording certain physical properties of gluten and wheat flour doughs. An analytical review of the scientific progress in this field has recently been presented by Bailey (1). Of the numerous devices described by him only the Brabender farinograph and the Swanson and Working recording dough mixer, which are designed to provide a graphical record of the force required to mix a dough, have been extensively used as yet on this continent. Recently, however, the Brabender extensograph, a machine designed to measure the extensibility of a dough and its resistance to extensibility, has been placed on the American market.

The studies of Markley and Bailey (17) and of Geddes, Aitken, and Fisher(5) indicate that the characteristics of the Brabender farinogram are not closely related to baking strength, as measured by loaf volume. In their original paper, Swanson and Working point out that flours from certain varieties gave characteristic curves, and more recently Larmour, Working, and Ofelt (16) and Larmour (15) have pointed out that such devices are valuable in establishing qualitative differences between doughs.

It is interesting to note, after a study of available comparative data on hard winter and hard spring wheats, that Larmour (15) reaches the conclusion that these two classes of wheat are essentially equal in loaf volume-producing ability when compared on an equivalent protein basis, but that they differ materially in dough characteristics, mixing and fermentation, and oxidizing requirements. In general, winter wheat flours yield a "softer" type of dough and require less mixing and fermentation than spring wheat flours to produce the optimum loaf.

As far as bread characteristics are concerned, there is considerable variation in the type of loaf preferred. In general, however, the demand is for a medium to large well risen loaf with a uniform break and shred. The crumb should have small uniform thin-walled cells which feel silky to the touch. The color of the crumb should preferably be creamy white but there is considerable variation in different localities and countries regarding the extent to which bread is discounted in the eyes of the consuming public for varying shades of yellowness. A dull or grey crumb color is particularly objectionable, however, since it cannot be corrected by flour bleaching.

OBJECTIVES IN BREEDING FOR MILLING AND BAKING QUALITY

The plant breeder will naturally endeavor to produce a high-yielding wheat of desirable physical properties which will grade well, but precisely what milling characteristics, baking strength, and baking characteristics should he strive for? These are perfectly logical questions and plant breeders naturally look to cereal chemists, millers, and bakers for guidance. They are confused no doubt by the evasive answers of cereal chemists and the varying preferences of millers and bakers who view quality from the standpoint of their individual requirements. The previous discussion of the various and complicated factors involved in milling and baking quality and the varying demands of different trades throw some light on the reasons for lack of definiteness and indicate the difficulty in setting forth objectives. If the plant breeder could, like the miller, select a particular trade for which to develop a wheat, the problem would be greatly simplified, but for many purposes spring and winter wheats are used interchangeably in the United States, selection being made on the basis of differing characteristics resulting from varying environmental conditions and price considerations.

An approach to a logical answer can be made if one considers that the milling and baking practices in any country, although variable, are in the long run adapted to the wheat which is available. As experience was gained general procedures were gradually developed which gave more or less optimum results with the material at hand. With large areas devoted to the culture of one or at least only a few varieties, a situation which existed when wheat production first became important in the Great Plains area, the wheat was uniform in characteristics and it was a much simpler matter for the miller to turn out a uniform flour which is so essential in maintaining a trade. As new varieties were introduced, which in some instances required different tempering treatment to secure optimum milling and also modifications in processing conditions during baking, the millers' difficulties in maintaining smooth operation of their mills and in producing a uniform flour were increased. This is a very valid reason why the miller prefers that only a few varieties should be grown and views with no little concern the release of new ones which inevitably differ more or less from the old in some respects.

Where the present types are satisfactory in quality, then the objective of the plant breeder is plain. He should devote his efforts to producing a wheat with the desired agronomic characteristics, resistance to insects and diseases, etc., which is as nearly similar as possible in milling and baking characters to those with which the trade is accustomed. New varieties possessing characteristics which differ widely from the normal run of wheat, even though they are superior if given the right treatment, will cause trouble when they come on the market in varying amounts and mixtures.

This policy of endeavoring to produce new wheats with milling and baking characteristics similar to a representative standard variety of the same class of wheat involves very extensive testing of the variety in comparison with the standard. It is important to achieve a much greater degree of certainty than in many other

classes of work. Experimental milling and baking tests should be carried out in a number of laboratories, as emphasized by Swanson (22). These should be supplemented by at least small-scale commercial tests. The cooperation of the miller and the mill chemist is required since it gives workers in institutions a knowledge of the requirements of the trade and may uncover some points of quality which have been overlooked or are not readily ascertainable from purely laboratory tests. Commercially sponsored crop improvement associations provide a convenient liasion between institutional workers and the trade.

The interpretation of the results and the judgment used in taking final action are equally important to thorough quality testing. There seems to have grown up a philosophy among some workers that if by appropriate variations in test procedure which suit the pecularities of the sample, a variety will yield an acceptable loaf of bread it should be regarded as acceptable. While such a view may be logical from the standpoint of relative baking strength, it is a dangerous doctrine to apply in variety testing. Such a wheat would lower the uniformity of the crop and multiply the difficulties of the trade. The new variety should give satisfactory, and preferably optimum, results in milling and baking when processed in the same manner as the "standard variety" of the same wheat class. In this connection it is important to note that definite "inferiority" in any one important quality characteristic is sufficient to render the variety unsuitable for release, even though it may be regarded as superior to the "standard" variety in other particulars. Thus, higher flour-yielding ability cannot offset inferior baking properties, or good loaf volume, undesirable dough characteristics.

From the standpoint of the grain trade, the number of varieties should be as few as possible. New wheats have been urgently required to meet the ravages of plant diseases and to provide wheats of desirable agronomic properties for various soil and climatic conditions; changing agricultural conditions or quality requirements will undoubtedly continue the need for new varieties for many years to come. Once the important cultural hazards have been met, the quality requirements for varieties subsequently developed should be even more rigidly adhered to and such varieties should be superior in one or more agronomic properties and equal in other properties to existing ones before distribution is considered. There is perhaps a tendency to release too many new hybrids which measure up fairly closely in agronomic and industrial quality characteristics to currently grown varieties.

In suggesting that the objectives of plant breeders should be to produce new varieties which are similar in milling and baking characteristics to those now grown, the writer does not wish to imply that imperfections, such as undesirable physical appearance and high yellow pigment content, should be reproduced nor that such desirable characteristics as mixing and fermentation tolerance should not be increased, but rather that the variety must give satisfactory, although not necessarily, but preferably, optimum, milling and baking results when treated according to present procedures if it is to meet with ready acceptance.

This concept of the objectives in breeding wheat for quality assumes that the varieties used as standards of reference are reasonably satisfactory, that the new wheat is designed for the same market, and that the quality requirements of the market in question will remain constant over the period of years required to develop and introduce the new variety. It is, of course, impossible to predict whether the hard wheats of the United States will be consumed largely in the United States in the next two decades, or whether the quality requirements of foreign markets should be considered in developing new wheats. In this connection it is of interest to note that Tenmarq, a winter wheat developed at Kansas State College several years ago, and Marmin, a recently introduced winter wheat variety developed at the University of Minnesota, were produced from crosses with a spring wheat as one of the parents. As would be anticipated, these varieties show excellent baking strength and apparently have longer mixing and fermentation requirements and greater tolerance in these respects than the older winter wheat varieties. The dough characteristics also appear to approach more nearly those of spring wheat flours. In these new wheats we have examples of the development of varieties which would probably be more suitable for blending with weak European wheats than some other varieties of hard winter wheat.

Technological changes may result in a preference for wheat with different quality characteristics than the characteristics which are desired today. Indeed, within the past few years there appears to be a trend towards the use of flours of somewhat shorter mixing and fermentation requirements for the manufacture of "pan" bread than the strongest available flours require. It has been privately suggested that plant breeders should devote their efforts to producing wheats which require less processing in these respects. It must be remembered, however, that for a number of years, climatic conditions in the Great Plains area have favored the production of high protein, strong wheats and it would seem unwise to change radically our wheat breeding policy until it is certain that the present trends toward the use of "weaker" flours are to continue and that "normal" weather conditions will not produce the type of wheat desired.

Scientific and technological advances may quite radically influence quality objectives and plant breeders and cereal chemists must keep in close touch with developments in industry. It is not unlikely that in the future additional objectives may be superimposed on those outlined here. Indeed, at the moment, the problem of remedying certain deficiencies in the average American diet is attracting the lively interest of nutrition workers, cereal chemists, millers, and bakers. Nutritionists regard wheat flour as a natural and proper medium for remedying vitamin B_1 (thiamin) deficiency in the national diet and standards are about to be set up by the Food and Drug Administration to provide for the proper and constructive promotion of vitaminized flour. The milling industry has given its active support to this program and is carefully considering the operating and merchandizing technics necessary to conform to such new standards as may finally be decided upon. These developments may probably lead to the manufacture of longer extraction flours in order

to retain the greatest possible quantities of the desired nutrient elements that are naturally present in the wheat, coupled with the addition of these nutrient elements to the finished flour. Accordingly, the baker and the consuming public may shortly arrive at different standards of bread quality than appear to be accepted at present. It may well be that a demand will also arise for the breeding of wheats of high vitamin content. As far as vitamin B_1 is concerned it does appear, from the limited data available, that different classes and varieties of wheat show considerable variation, thus suggesting the possibility of varying the thiamin content by plant breeding.

SUMMARY

The industrial quality of hard wheats depends upon their milling quality and the value of the flour for bread making purposes.

The efficiency of the grading system would be greater and the market evaluation of wheat simplified if certain physical properties (kernel color, texture, vitreousness, test weight) and protein content of all varieties within a wheat class uniformly reflected their intrinsic value, but unfortunately this is not always true.

For good milling quality, the kernels should be plump, uniformly large in size to permit ready separation of foreign material, absorb water readily and uniformly in the tempering process, and produce a high yield of flour of low yellow pigment and ash content with a maximum and clean separation from the bran and germ without undue consumption of power. Milling characteristics cannot be determined with any degree of precision on small batch-type experimental mills.

Baking quality is defined as the sum of excellence on several points and includes the production of satisfactory bread over a considerable range of baking conditions, the facility with which large masses of dough can be handled in the bakery, and the bread yield obtainable, whereas baking strength refers to inherent capabilities of the material as measured by loaf volume under optimum conditions. In general, strong flours yield "tough" doughs requiring more mixing and fermentation and having greater tolerance to variations in these factors than weaker flours, but the parallel between loaf volume-producing ability, dough handling properties, and processing requirements does not hold for certain varieties.

Baking quality is determined by using different formulas and procedures which, under ideal conditions, are so designed as not only to reveal the inherent strength of the sample but also to secure a measure of the baking conditions, such as extent of mixing, length of fermentation and oxidation requirements, and the range of each of these which affect the production of the optimum loaf. Handling properties of the dough are of particular importance in relation to the value for blending with weak wheats. The variety should yield a flour which is "well balanced" in regard to the various attributes of quality.

Commercial testing of new varieties is advisable and the cooperation of the miller and mill chemist is essential to give workers in wheat breeding stations a knowledge of the requirements of the trade and to

uncover points of quality which may have been overlooked or are not readily ascertainable from purely laboratory tests.

Where the present types of wheat are satisfactory in quality, the plant breeder should endeavor to produce wheat with the desired agronomic characteristics, resistance to insects, diseases, etc., which are as similar as possible in grading, milling, and baking characteristics to the superior present varieties. New varieties with different processing requirements make it difficult for the miller to deal with mixtures and produce flour of uniform and desired characteristics.

In the interests of uniformity, a new variety should not be released for distribution unless it is superior to the present varieties in one or more agronomic characters or disease resistance and is satisfactory in all other respects.

The objectives in breeding hard wheat for quality depend on quality requirements of the market and scientific and technological advances may change these requirements or introduce new factors and close contact with the milling and baking industry is essential. Current developments related to increasing the nutritional value of flour may change materially flour quality requirements and lead to a demand for the breeding of wheats of high vitamin content.

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SMALL GRAINS AND WINTER LEGUMES GROWN MIXED FOR GRAIN PRODUCTION[1]

J. S. Papadakis[2]

WHEN two plants grow near to each other they are mutually injurious. In herbaceous plant communities this injury is attributed (10, 11)[3] principally to toxins excreted by the living roots. These toxins render the soil unsuitable for root growth, hence plants require space for root expansion. For this reason there is no advantage in increasing the number of plants per unit area beyond certain limits and for the same reason, since the toxins are not specific (11), there would seem to be no advantage in growing plants of different species together.

But space is not always a limiting factor. If environmental conditions are unfavourable to the growth of a crop, and if as a result growth is stunted and the plants do not occupy all the available space, there remains space for the growth of other plants better adapted to the prevailing conditions. If the crop consists of plants of only one species, the remaining space may be occupied by weeds and at any rate is lost to the farmer. On the other hand, if the crop is composed of two species differing considerably ecologically, the species better adapted to the prevailing conditions will occupy the space left free by the species less well adapted and all the space will be utilized. The result is as though the farmer knew beforehand the weather which would prevail during the whole period of growth and chose the crop accordingly.

The automatic adjustment of the crop to the season is very important. Not only do meteorological conditions vary from season to season, but also do edaphic conditions, especially the immediate fertility of the soils, i.e., the amount of immediately available nitrogen. If the crop mixture includes a plant very sensitive to nitrogen supply, such as a cereal, and a plant less sensitive, as a legume, the non-leguminous plant dominates in seasons favoring nitrogen accumulation, and the leguminous plant in seasons unfavorable to nitrogen accumulation, the crop thus automatically adjusting itself to the nitrogen supply.

There are other advantages of a cereal and legume mixture. It is known, for example, that plant roots excrete substances which by favoring microbial activity render the soil poorer in available nitrogen (5). On the other hand, roots of leguminous plants excrete nitrogen (13, 14, 15, 16, 17). Consequently, when cereals and legumes are grown together, the former are favored by the fact that their neighbors do not impoverish the soil in available nitrogen but may even enrich it, while the latter are not materially damaged because they are somewhat independent of the soil nitrogen supply.

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[1]Contribution from Institute of Plant Breeding, Thessaloniki, Greece. Received for publication October 15, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 510.

For these reasons, therefore, the question of growing a mixture of cereals and legumes merits attention. Many writers (1, 2, 3, 4, 13, 14, 15, 16, 17) have studied the question, and although not entirely in agreement in their conclusions, all of their experiments show that the yield of the mixture is equal to or higher than the average of the yields of the two plants grown alone.

In practice the method was long ago applied on prairies and in forage crops. Mixtures of summer cereals and legumes are also grown extensively. Mixtures of small grains with winter legumes, however, are not generally grown for grain.

In order to study this phase of the question which has great practical interest, experiments were begun in 1937. In the experiments of the first year, reported in another paper (8), the wheat produced by the mixtures was about equal to that produced by wheat grown alone, and in addition the mixture produced a considerable quantity of grain from the legume (*Ervum ervillia*). Wheat sown on these plots the second year gave a yield 47% higher on the plots sown the preceding year with the mixture than on the plots sown with wheat alone (9). In the experiments of the second year (9), the wheat produced by the mixtures sown in seven locations was, in general, less than that produced by wheat sown alone, but for every kg reduction of wheat grain there were increases of 4.7 kg of *Ervum ervillia* grain and 6.1 kg of straw.

The present paper presents the results of the third year of the experiment.

FIELD EXPERIMENTS

In order to study the yield of the mixtures and their influence on immediate fertility and on the fertility level, rotation experiments were begun in 1939 at the Institute at Thessaloniki and at five substations. Besides these experiments which were carried out in the field, analogous pot experiments were begun at the Institute. The results of the first year (Tables 1 and 2) show only the yield of the mixtures in comparison with the results where the plants were grown alone.

The soils were poor. As a general average of all mixtures and all stations, the cereal grain produced by the mixture was 61% more than the grain produced by ½ hectare[4] of the cereal grown alone. On the other hand, the grain of the leguminous plant produced by 1 hectare of the mixture was 9% less than that produced by ½ hectare of the legume grown alone. The total grain yield of the mixture was 21% higher than the average of the yields of the two plants grown alone.

The results were better with wheat than with oats. Oats profited equally well by the association (291 against 296) but caused greater reduction of legume yield 96 against 13. The results were better with lupine than with ervum or lathyrus.[5]

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[4]A hectare is equivalent to 2.471 acres.

[5]Lupine increased the yield of wheat while its own yield was not reduced.

TABLE 1.—*A comparison of yields of small grains and leguminous plants grown in combination and singly.*

Mixture	Repetition*	In combination†			Singly‡			Difference		
		Cereal	Legume	Total	Cereal	Legume	Total	Cereal	Legume	Total
Thessaloniki										
Wheat + Ervum	8-45-22	1,150	40	1,190±143	695±30	240±17	935	455	-200	255
Wheat + Lathyrus	3-45-16	860	150	1,010±234	695±30	590±59	1,285	165	-440	-275
Wheat + Lupine	5-45- 8	1,330	20	1,350±180	695±30	120±30	815	635	-100	535
Av., wheat + legume	16-45-46	1,113	70	1,183±101	695+30	317±23	1,012	418	-247	172
Oats + Ervum	9-11-22	1,470	20	1,490±135	785±61	240±17	1,025	685	-220	465
Oats + Lathyrus	5-11-16	1,260	150	1,410±180	785±61	590±59	1,375	475	-440	35
Oats + Lupine	5-11- 8	1,610	20	1,630±180	785±61	120±30	905	825	-100	725
Av., oats + legume	19-11-46	1,447	63	1,510± 93	785±61	317±23	1,102	662	-253	408
Av., cereals + legume	35-56-46	1,280	66	1,346± 68	740±54	317±23	1,057	540	-250	290
Larissa										
Wheat + Ervum	3-6-2	1,370	260	1,630±153	685±54	635±93	1,320	685	-375	310
Wheat + Lathyrus	4-6-2	1,010	550	1,560±132	685±54	710±93	1,395	325	-160	165
Wheat + Lupine	3-6-2	1,220	740	1,960±153	685±54	795±93	1,480	535	- 55	480
Av., wheat + legume	10-6-6	1,200	517	1,717± 84	685±54	713±54	1,398	515	-197	318
Oats + Ervum	2-5-2	1,030	180	1,210±186	665±59	635±93	1,300	365	-455	- 90
Oats + Lathyrus	1-5-2	980	440	1,420±265	665±59	710±93	1,375	315	-270	45
Oats + Lupine	2-5-2	980	690	1,670±186	665±59	795±93	1,460	315	-105	210
Av., oats + legume	5-5-6	997	437	1,433±118	665±59	713±54	1,378	332	-276	56
Av., cereals + legume	15-11-6	1,098	477	1,575± 68	675±39	713±54	1,388	423	-236	187
Dourouti										
Wheat + Ervum	3-6-2	270	690	960±139	175±49	710±120	885	95	- 20	75
Wheat + Lathyrus	4-6-2	120	1,390	1,510±120	175±49	1,210±210	1,385	- 55	180	125
Wheat + Lupine	3-6-2	40	2,100	2,140±139	175±49	1,585±85	1,760	-135	515	380
Av., wheat + legume	10-6-6	143	1,393	1,537± 76	175±49	1,168±85	1,343	- 32	225	193
Oats + Ervum	2-5-2	320	320	640±169	220±54	710±120	930	100	-390	-290
Oats + Lathyrus	1-5-2	310	1,550	1,860±240	220±54	1,210±210	1,430	90	340	430
Oats + Lupine	2-5-2	110	2,050	2,160±169	220±54	1,585±85	1,805	-110	465	355
Av., oats + legume	5-5-6	247	1,307	1,553±107	220±54	1,168±85	1,388	27	138	165
Av., cereals + legume	15-11-6	195	1,350	1,545± 62	197±36	1,168±85	1,365	- 2	182	180

Kaladzopoulou (Tripolitsa)										
Wheat + Ervum	3–6–2	620	470	1,090±105	330±37	515±64	845	290	− 45	245
Wheat + Lathyrus	4–6–2	340	1,940	1,280± 90	330±37	910±64	1,240	10	30	40
Wheat + Lupine	3–6–2	240	2,130	2,370±105	330±37	1,180±64	1,510	− 90	950	860
Av., wheat + legume	10–6–6	400	1,180	1,580± 57	330±37	868±37	1,198	70	312	382
Oats + Ervum	2–5–2	1,220	40	1,260±128	630±40	515±64	1,145	590	−475	115
Oats + Lathyrus	1–5–2	810	680	1,490±181	630±40	910±64	1,540	180	−230	−50
Oats + Lupine	2–5–2	730	1,710	2,440±128	630±40	1,180±64	1,810	100	530	630
Av., oats + legume	5–5–6	920	810	1,730± 81	630±40	868±37	1,497	290	− 58	232
Av., cereals + legume	15–11–6	660	995	1,655± 47	480±27	868±37	1,348	180	127	307
Messara										
Wheat + Ervum	3–6–2	260	590	850± 50	210±17	635±30	845	50	− 45	5
Wheat + Lathyrus	4–6–2	200	550	750± 43	210±17	485±30	695	− 10	65	55
Wheat + Lupine	3–6–2	360	0	360± 50	210±17	0	210	150	0	150
Av., wheat + legume	10–6–6	273	380	653± 27	210±17	373±18	583	63	7	70
Oats + Ervum	2–5–2	410	600	1,010± 61	310±19	635±30	945	100	− 35	65
Oats + Lathyrus	1–5–2	420	520	940± 86	310±19	485±30	795	110	35	145
Oats + Lupine	2–5–2	820	0	820± 61	310±19	0	310	510	0	510
Av., oats + legume	5–5–6	550	373	923± 38	310±19	373±18	683	240	0	240
Av., cereals + legume	15–11–6	411	376	788± 22	260±13	373±18	633	151	3	154
Ptolemaide										
Wheat + Ervum	3–6–2	1,310	0	1,310± 93	710±33	0	710	600	0	600
Wheat + Lathyrus	4–6–2	1,510	160	1,670± 81	710±33	170±97	880	800	−10	790
Wheat + Lupine	3–6–2	1,540	400	1,940± 93	710±33	915±20	1,625	830	−515	315
Av., wheat + legume	10–6–6	1,453	187	1,640± 51	710±33	362±22	1,072	743	−175	568
Oats + Ervum	2–5–2	310	0	310±115	385±36	0	385	−75	0	−75
Oats + Lathyrus	1–5–2	650	70	720±115	385±36	170±97	555	265	−100	165
Oats + Lupine	2–5–2	790	630	1,420±115	385±36	915±20	1,300	405	−285	120
Av., oats + legume	5–5–6	583	233	816± 72	385±36	362±22	747	198	−128	70
Av., cereals + legume	15–11–6	1,018	210	1,228± 42	547±49	362±22	909	471	−152	319
Average of All Stations										
Wheat + Ervum	23–75–32	830	342	1,172	467	456	923	362	−114	248
Wheat + Lathyrus	23–75–26	673	623	1,297	467	679	1,147	206	− 56	150
Wheat + Lupine	20–75–18	788	898	1,687	467	766	1,233	321	132	453
Av., wheat + legume	66–75–76	764	621	1,385	467	634	1,101	296	− 13	284
Oats + Ervum	19–36–32	793	193	987	499	456	955	294	−262	32
Oats + Lathyrus	10–36–26	738	568	1,307	499	679	1,178	239	−111	128
Oats + Lupine	15–36–18	840	850	1,690	499	766	1,265	341	84	425
Av., oats + legume	44–36–76	790	537	1,328	499	634	1,133	291	− 96	195
Av., cereals + Ervum	42–111–32	811	267	1,079	483	456	939	328	−188	140
Av., cereals + Lathyrus	33–111–26	705	595	1,302	483	679	1,162	222	− 83	139
Av., cereals + Lupine	35–111–18	814	874	1,688	483	766	1,248	331	108	439
Av., cereals + legume	110–111–76	777	579	1,356	483	634	1,117	297	− 54	239

*The first number shows the repetitions of the mixture, the second the repetitions of the small grain grown singly, and the third the repetitions of the leguminous plant grown single.
†Yields in kilograms per hectare. (To convert into pounds per acre, multiply by 0.892.) ‡Yields per ½ hectare.

TABLE 2.—*Comparison of small grains and leguminous plants grown in combination and singly in pots, with yields in grains per pot.*

Mixture	Repetitions*	In combination			Singly†			Difference		
		Cereal	Legume	Total	Cereal	Legume	Total	Cereal	Legume	Total
Wheat + *E. ervillia*.....	45–256–149	2.89 ±0.22	14.32 ±0.75	17.21 ±0.65	2.73 ±0.14	9.95 ±0.40	12.68 ±0.42	0.16 ±0.26	4.37 ±0.85	4.53 ±0.77
Wheat + *E. lens*.......	6–256–	3.15 ±0.51	12.63 ±1.81	15.78 ±1.72	2.73 ±0.14	—	—	0.42 ±0.53	—	—
Wheat + Lathyrus.....	27–256–100	4.04 ±1.58	8.13 ±0.66	12.16 ±0.78	2.73 ±0.14	6.88 ±0.47	9.61 ±0.48	1.31 ±1.59	1.25 ±0.81	2.55 ±0.92
Wheat + Lupine.......	12–256–41	7.40 ±0.73	2.43 ±0.67	9.82 ±0.84	2.73 ±0.14	1.69 ±0.39	4.42 ±0.41	4.67 ±0.74	0.74 ±0.78	5.40 ±0.93
Av., wheat + legume‡..	84–256–290	4.78 ±0.58	8.29 ±0.40	13.06 ±0.44	2.73 ±0.14	6.17 ±0.24	8.90 ±0.28	2.05 ±0.60	2.12 ±0.47	4.16 ±0.52
Oats + *E. ervillia*......	38–57–149	4.16 ±0.36	13.72 ±0.65	17.89 ±0.64	4.35 ±0.39	9.95 ±0.40	14.30 ±0.56	−0.19 ±0.53	3.77 ±0.76	3.59 ±0.85
Oats + Lathyrus.......	21–57–100	6.98 ±0.60	6.08 ±0.50	13.06 ±0.65	4.35 ±0.39	6.88 ±0.47	11.23 ±0.60	2.63 ±0.72	−0.80 ±0.69	1.83 ±0.88
Oats + Lupine........	7–57–41	8.98 ±0.64	2.78 ±1.24	11.75 ±1.56	4.35 ±0.39	1.69 ±0.39	6.04 ±0.55	4.63 ±0.75	1.09 ±1.30	5.71 ±1.65
Av., oats + legume....	66–57–290	6.71 ±0.31	7.53 ±0.50	14.23 ±0.60	4.35 ±0.39	6.17 ±0.24	10.52 ±0.46	2.36 ±0.50	1.36 ±0.55	3.71 ±0.76
Av., cereals + *E. ervillia*	83–313–149	3.52 ±0.21	14.02 ±0.50	17.55 ±0.46	3.54 ±0.21	9.95 ±0.40	13.49 ±0.45	−0.02 ±0.30	4.07 ±0.64	4.06 ±0.64
Av., cereals + Lathyrus	48–313–100	5.51 ±0.85	7.10 ±0.41	12.61 ±0.50	3.54 ±0.21	6.88 ±0.47	10.42 ±0.51	1.96 ±0.88	0.22 ±0.62	2.19 ±0.71
Av., cereals + Lupine..	19–313–100	8.19 ±0.48	2.60 ±0.70	10.78 ±0.89	3.54 ±0.21	1.69 ±0.39	5.23 ±0.44	4.65 ±0.52	0.91 ±0.80	5.55 ±0.99
Av., cereals + legume..	150–313–290	5.74 ±0.33	7.91 ±0.32	13.65 ±0.37	3.54 ±0.21	6.17 ±0.24	9.71 ±0.32	2.20 ±0.39	1.74 ±0.40	3.94 ±0.49

*The first number shows the repetitions of the mixture, the second the repetitions of the small grain grown singly, and the third the repetitions of the leguminous plant grown single.

†Yields for ½ pot only.

‡Wheat + *Ervum lens* not included.

POT EXPERIMENTS

The results of the pot experiments are in perfect agreement with those of the field experiments and proved even more favorable to the mixtures. The results were better with wheat than with oats, with lupine than with *Ervum ervillia* or lathyrus, and the best results were obtained with the mixture of wheat and lupine.

When for one reason or another the cereal or the legume sown alone failed, the yield of the mixture approached or even surpassed that of the complementary plant sown alone.

Table 3 shows the coefficient of variability of the yields from station to station for the field experiments and from pot to pot for pot experiments. The yield of the mixtures was almost always less variable than that of the less variable of their constituents. Consequently, mixtures are less hazardous than single crops.

Another advantage of the mixtures was that leguminous plants being less aggressive than cereals are often suppressed by weeds. The relatively good yields obtained in our experiments with leguminous crops sown alone were due to frequent hoeings which would be impossible in practice. Mixtures resemble in this respect the more aggressive of their constituents, i.e., the cereal.

Great areas were sown to mixed plantings in 1940, both by the Institute and by farmers to whom the procedure was recommended. The mixture of wheat and *Ervum ervillia* is easily harvested with an ordinary grain binder and threshed with an ordinary grain thresher. With lupine the question of threshing cannot be considered as solved. The two crops mature about at the same time. The wheat varieties grown in Greece do not shatter. The seeds of the two crops are mixed in equal quantities and drilled in. In the 1938 experiments (8) sowing in the same rows gave better results than sowing the crops in alternate rows. The seeding rate is 50% higher than usually; in our experiments 75 kg of wheat and 50 kg of *Ervum ervillia* as compared with 100 kg of wheat sown alone.

TABLE 3.—*Coefficient of variability of the yields of the mixtures and of the plants grown singly.*

Mixture	From station to station (field)			From pot to pot		
	Cereal	Legume	Mixture	Cereal	Legume	Mixture
Wheat + Ervum	54%	63%	24%	38%	24%	25%
Wheat + Lathyrus	54%	53%	28%	38%	34%	33%
Wheat + Lupine	54%	80%	42%	38%	75%	30%
Oats + Ervum	45%	63%	44%	33%	24%	22%
Oats + Lathyrus	45%	53%	31%	33%	34%	23%
Oats + Lupine	45%	80%	34%	33%	75%	35%
Average	49%	65%	34%	33%	44%	28%

SUMMARY

In extensive experiments 1 hectare of a mixture of cereal and winter legume produced about 60% more cereal grain than ½ hectare of

cereal sown alone, and at the same time produced a quantity of leguminous grain almost equal to that of ½ hectare of the leguminous plant sown alone.

In cases in which the cereal or the leguminous plant sown singly failed, the mixture gave a yield approaching and sometimes surpassing that of the complementary plant sown alone.

The yields of the mixtures were much less variable than those of the single crops.

For mixtures wheat seems better adapted than oats and lupine than *Ervum ervillia* or lathyrus. Preceding experiments showed peas to be less suitable than ervum.

The results are attributed to an automatic adjustment of the crop to the meteorological and edaphic conditions prevailing in each case, to the nitrogen excretion of the leguminous plants, and to the fact that leguminous plants compete less seriously with their neighbors for nitrogen than do other cereal plants.

In a preceding experiment, wheat following the mixture gave a much higher yield than where it followed wheat grown alone.

The mixture of wheat and *Ervum ervillia* can be harvested with ordinary grain binders and threshed with ordinary grain threshers. The two seeds are mixed and drilled together.

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SELF-FERTILITY IN RED CLOVER IN MINNESOTA[1]

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STUDIES of the effects of self-pollination with red clover, *Trifolium pratense* L., have been carried on at the Minnesota Experiment Station since 1923. Although the number of plants selfed during any one season has not been very great the total number of self-pollinations has afforded a fair sampling of the extent of seed setting under bags in this crop.

The purpose of the present paper is to record the origin of a self-fertile line and to summarize studies of inheritance of self-fertility, leaf-marking, and date of flowering in the F_2 population of a cross between the self-fertile line and a self-sterile commercial variety of medium red clover.

From previous investigations (2, 4)[3] most of the red clover plants studied have been found to be rather highly self-sterile, although enough selfed seed can be obtained to enable an estimation of the effects of continual inbreeding in red clover. Seed setting is usually so low that selection in self-pollinated lines cannot be used as a method of improvement.

Pieters and Hollowell (5) and Williams (6) have found that some red clover plants set several selfed seeds but that the progenies may not necessarily be self-fertile. This phenomenon has been termed pseudo-self-fertility.

Self-fertile lines of red clover have also been established by Williams in Wales and by Fergus in Kentucky (5). Self-sterility in red clover is due to the inability of the pollen to penetrate the style and reach the ovule before the egg has disintegrated (6). Williams and Silow (7) have explained self-sterility in red clover by the "Oppositional Factor Hypothesis" as advanced by East and Mangelsdorf (1) in interpreting their data on cross-incompatibility in *Nicotiana* spp. Williams (6) has found 34 different sterility alleles from a study of 20 red clover plants, thus indicating that this allelic series is very extensive. Gmelin and Wexelsen have previously shown that a cresent-shaped leaf marking was dominant over non-marking and would segregate in a 3:1 ratio in an F_2 population (5).

MATERIAL AND METHODS

In 1928 a relatively highly self-fertile plant occurred in the fifth generation of selfing of a commercial red clover variety. Although there have been wide seasonal differences in the amount of seed set, this self-fertile line has been maintained easily by self-pollination for 15 generations and has bred true for self-fertility. This line, not nearly as vigorous as normal red clover, bears a non-

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[3]Figures in parenthesis refer to "Literature Cited", p. 521.

marked leaf and blossoms about 3 weeks later than the commercial variety from which it was obtained.

The original crosses for the inheritance study were made under greenhouse conditions using the self-fertile inbred line as the male parent and several plants of the self-sterile variety which carries the dominant gene for leaf-marking as the female parent.

Crosses were made without emasculation by applying pollen with a toothpick. Parental plants were selfed, but seed was obtained only in the self-fertile line, indicating that the plants of the commercial variety used as females were self-sterile. All of the plants used in this study were grown from seedlings started in the greenhouse in the spring and transplanted to the field when conditions became favorable. All self-pollinations were made under field conditions. Selfing was accomplished by enclosing individual heads, before anthesis, in a 2¾ inch × 4 inch × 3½ inch cloth mesh bag which was tied securely around the stem of the blossom. Each of the F_1 plants readily set selfed seed, thus indicating that all were crosses.

Studies of self-fertility were made using, whenever possible, 12 heads on each F_2 plant. Three of the heads were allowed to set open-pollinated seed, whereas the other nine were protected from cross-pollination. Three of the protected heads were allowed to set seed without manipulation of the heads, three were rolled back and forth between the forefinger and thumb without removing the bag when from one-half to three-quarters of the florets were in bloom, and the other three were manipulated by removing the bag and tripping approximately 25 florets per head with a toothpick. Tripping was accomplished by applying pressure on the keel, thus releasing the stamens and stigma from within the keel. The bags were then replaced and fastened as before and each head was marked as to type of treatment received. The heads were harvested when ripe and the seed count was made for each head threshed individually.

The extent of self-fertility is expressed as a percentage of the open-pollinated seed set. This was determined by averaging the seed set per head of the rolled and tripped heads and dividing by the average open-pollinated seed set per head for the same plant.

About 1 month after transplanting into the field the number of plants with and without leaf markings were counted. A plant having any indication of a leaf crescent was considered as marked. In analyzing the data X^2 was used and the values of P determined from Fisher's tables (3).

The date of flowering was recorded as each plant came into bloom. A plant was considered to be in bloom when it had three heads fully open; or, if a plant was weak due to chlorophyll deficiency or for some other reason, it was considered to be in flower when only a single head was fully blossomed.

EXPERIMENTAL RESULTS

DEVELOPMENT OF THE SELF-FERTILE LINE

In 1923, L. E. Kirk started a study at the Minnesota Experiment Station which he carried on for two generations to determine the effects of self-fertilization of red clover (4). From 1925 to 1934 self-pollination and selection were continued at the Minnesota Station by various workers. After 5 years of selfing a plant was obtained which was considerably more self-fertile than the others. The average number of selfed seed set per head for this plant was 29, whereas

48.3 was the average open-pollinated seed set per head for the same plant. A sister plant in the same line set 0.2 selfed seed and 27.5 open-pollinated seed per head. Of the 74 plants that were selfed that year the second largest amount of selfed seed set was 10.7 seeds per head. The progenies of this latter plant in later generations were apparently self-sterile.

In Table 1 is presented a summary of seed setting in the self-fertile line for 11 generations of selfing. It is to be noted that with the exception of the seventh generation the amount of selfed seed set in this line was relatively large when compared with amounts set previous to the development of self-fertility. The small amount of seed set under both open and selfed conditions in the seventh year of selfing occurred during an exceptionally dry season.

TABLE 1.—*Seed setting in a self-fertile line.*

Years selfed	No. of plants selfed	Number of seeds per head					
		Av. of line		Range of line		Plant selected	
		Selfed	Open	Selfed	Open	Selfed	Open
1	2	4.4	—	4.2– 4.7	—	4.2	—
2	10	2.1	—	0.6– 2.8	—	1.9	—
3	5	3.7	—	1.0–10.7	—	10.7	—
4	15	0.1	13.2	0 – 1.0	1.2–25.2	1.0	15.0
5	2	14.6	37.9	0.2–29.0*	27.5–48.3	29.0	48.3
6	3	16.7	17.8	13.2–20.0	13.3–25.0	13.2	25.0
7	2	2.5	4.9	1.3– 3.7	3.2– 6.6	3.7	6.6
8	3	46.1	57.9	26.2–67.0	35.0–72.7	45.2	72.7
9	7	19.9	63.6	2.0–38.3	35.0–100.0	23.3	60.0
10	2	23.8	37.8	17.5–30.3	30.0–45.0	17.5	30.4
11	3	21.8	14.2	13.0–37.5	7.0–21.5	37.5	21.5

*Self-fertility appeared.

Plants from the commercial variety as well as those of the self-fertile line were selfed each year. The results are given in Table 2 in the form of a frequency distribution.

It is to be noted that there are seven plants among the commercials which showed as high or a higher percentage of self-fertility than did the original self-fertile plants. These plants evidently were pseudo-self-fertile as they were classified as self sterile in the following generations.

INHERITANCE OF SELF-FERTILITY

The seed setting of the F_1 generation and of the commercial plants grown in comparison is given in Table 3.

Seed setting percentages of 11 F_1 plants based on the average seed production of rolled and tripped heads in relation to open-pollinated heads ranged from 10 in C-11 to 110.5 in C-30, with an average of 46.5. The range of seed setting in 22 commercial plants was from 0% in 10 of the plants to 114.4% in No. 19, with an average of 2.4% for the entire commercial population. It is to be noted that the

second highest percentage of selfed seed set in the commercial plants was 9.5 which is lower than C-11, the lowest of the F_1 plants. The high percentage of plant No. 19 is partially due to the absence of seed setting in one of the open-pollinated heads of this plant and the consequent lowering of the average seed set per open-pollinated head. All of the F_1 plants except C-11 appeared to be self-fertile and this plant with 10% fertility was 76% more fertile than the average of the normal plants.

TABLE 2.—*Frequency distribution of commercial and self-fertile line plants as determined by expressing the amount of selfed seed as a percentage of open-pollinated seed set.*

Gen. self.	Year grown	No. of plants in classes with the following centers based on percentage seed set in terms of 100 for open-pollinated										
		2.5	10	20	30	40	50	60	70	80	90	100†
						Selfed Line						
4	1927	15*	—	—	—	—	—	—	—	—	—	—
5	1928	1*	—	—	—	—	—	1†	—	—	—	—
6	1929	—	—	—	—	—	—	—	1	1	—	1
7	1930	—	—	—	—	—	1	1	—	—	—	—
8	1931	—	—	—	—	1	1	1	—	—	—	—
9	1932	—	—	4	—	2	—	—	1	—	—	—
10	1933	—	—	—	—	—	—	—	—	1	—	—
11	1934	—	—	—	—	—	—	1	—	—	1	2
						Commercial Line						
0	1927	—	—	—	—	—	—	—	—	—	—	—
0	1928	14	2	2	—	—	—	—	—	—	—	—
0	1929	9	3	2	—	—	—	—	—	—	—	—
0	1930	4	2	1	1	—	1	—	—	1	—	—
0	1931	3	—	1	1	—	—	—	—	2	—	1
0	1932	11	1	—	—	—	—	—	—	—	—	—
0	1933	1	1	—	—	—	—	1	—	—	1	—
0	1934	5	—	1	—	1	—	1	—	—	—	—

*Selfed plants not bearing self-fertility gene.
†Self-fertility gene appeared in this plant.

Seed setting of the commercial plants and of the F_2 progeny of the crosses between commercial plants and the self-fertile line is given in Table 4.

Of the 30 commercial plants, 28 fell in the class 0–5% and 2 in the class 6–20%, whereas of the 179 F_2 plants only 4 were in the 0–5% class, 23 in the 6–20% class, and of the remainder 41 were in the modal class of 36–50% with an average of 61.2 for the F_2. Comparing these results with the F_1 population, one notes that the average fertility of the F_2 generation is somewhat greater than that of the F_1.

In order to eliminate the possibility that the very great increase in fertility in some plants was not due to the smaller amount of open-pollinated seed set per head in the F_2 population, the data were analyzed omitting all plants having less than an average open-pollinated seed set of 13.0 seeds per head. The figure 13.0 was selected because it was the lowest average seed set per head of the 30 normal

plants. Although this removed 41 plants from the analysis it did not noticeably change the distribution except to remove approximately one-half of the class above 125%. This class is exceptionally large because it has no upper boundary and because of the numerous plants contained in it that had a low production of open-pollinated seed.

TABLE 3.—*Seed setting of F_1 plants and of the commercial parent, three heads per treatment.*

Culture No.	Average seed set per head				Average of tripped and rolled in per cent of open-pollinated
	No treatment	Tripped	Rolled	Open-pollinated	
			F_1 Plants		
C-10	1	21	54	90	41.7
11	0	12	5	75	10.0
16	2	24	34	78	37.2
17	4	30	58	92	47.8
30	6	35	49	38	110.5
34	1	35	87	80	76.3
41	2	58	—*	81	71.6
43	—*	—*	—*	121	—
45	2	27	79	79	67.1
51	1	19	17	32	56.3
53	7	24	40	88	36.4
Average	2.6	28.5	47.0	77.6	46.5
			Commercial Plants		
1	0	0	0	24	0.0
2	0	0	0.3	40	0.4
3	0	0	0.7	23	1.5
4	3	0	0	19	0.0
5	0	0	0	22	0.0
6	0	0	0.3	45	0.3
7	0	0	4.0	48	4.0
8	0	0	0	11	0.0
9	0	0.3	0	49	0.3
10	0	0	0	46	0.0
11	0	0	3.7	21	9.5
12	4	1.7	0.3	21	4.8
13	0	0	0.3	40	0.4
14	0	0	3.3	39	4.2
15	0.7	1.3	2.0	43	4.0
16	0	0	0	25	0.0
17	0	0	0.3	53	0.3
18	0	0	0	45	0.0
19	0	7.0	11.3	8	114.4
20	0	0	0	46	0
21	0	0	0	61	0
22	0	0	0	35	0
Average	0.2	0.5	1.2	34.7	2.4

*Missing data.

It has been noted that among the commercial plants the highest yield of selfed seed was 15% of the open-pollinated seed set. Using

this as a basis for the upper limit of self-incompatibility, it was found that 28 plants of the 182 in the F_2 population were no more fruitful than the highest of the self-sterile plants in the commercial variety. However, by considering the seed yield of the individual heads per plant, it appeared that 17 of these 28 plants were self-fertile. Of the remaining 11 plants (Table 5), 4 produced scarcely any seed under any treatment. It seems probable that the lack of seed setting in these four plants may have been due to improper floral structure. Plants No. 41–28–6 and 41–30–8 produced seed under open-pollinated conditions only and the amount obtained was high. These two plants evidently were self-sterile and it is interesting to note that both came from the same family. Five plants, 11–13–2, 17–19–7, 34–24–4, 34–25–6, and 34–26–7, produced a few seeds per head under the various treatments, but their average seed set per head was much too low to be classified as self-fertile. These plants might be pseudo-self-fertile. It should be noted that the average open-pollinated seed set on each of these five plants was below average. Factors other than self sterility may therefore account for the low seed production on these plants.

TABLE 4.—*Frequency distribution of seed setting in the F_2 population and of the commercial parent on the basis of the average percentage of seed set in rolled and tripped heads of each plant in relation to the seed setting under open-pollinated conditions.*

F_2 culture No.	Number of plants in each class for seed setting of rolled and tripped heads in percentage of open-pollinated										Total
	0–5	6–20	21–35	36–50	51–65	66–80	81–95	96–110	111–125	125+	
10	0	1	0	6	7	2	2	3	1	4	26
11	0	4	1	2	1	0	0	1	0	0	9
16	0	1	4	4	2	3	1	3	1	3	22
17	0	3	0	13	5	0	4	0	0	2	27
30	0	2	0	1	1	3	2	2	1	2	14
34	0	4	3	2	3	2	1	0	0	3	18
41	2	1	3	6	2	1	1	1	0	2	19
43	0	2	0	1	0	3	2	0	0	1	9
45	0	1	1	5	1	1	1	0	0	1	11
51	1	2	3	1	3	1	2	0	0	1	14
53	1	2	3	0	1	2	0	0	0	1	10
Total.....	4	23	18	41	26	18	16	10	3	20	179*
Commercial variety	28	2	0	0	0	0	0	0	0	0	30

*Three plants which set no open-pollinated seed are omitted.

According to the multiple oppositional theory, including the Sf allele as applied to red clover by Williams, no self-sterile segregates should arise in an F_2 population from selfing a self-fertile F_1. Among the F_2 plants cited in this study at least two were definitely self-sterile. These apparently self-sterile plants might have arisen either by the union of gametes of S_x genotype in the F_1 plants, as has been shown to occur in pseudo-fertility, or by accidental outcrossing after

tripping by small insects capable of entering the mesh bags in which the heads were enclosed.

TABLE 5.—*Seed set per head on F_2 plants which could not be classified as self-fertile.*

Culture No.	No manipulation			Tripped			Rolled			Open pollinated			% of open pollinated
	1	2	3	1	2	3	1	2	3	1	2	3	
34-25-2	0	0	0	0	0	0	0	0	0	0	0	0	—
53-39-4	0	0	0	0	0	0	0	0	0	0	0	0	—
51-37-8	0	0	0	0	0	0	0	0	0	0	0	3	—
53-40-8	0	0	0	1	0	0	0	0	0	0	0	0	—
41-28-6	0	0	0	0	0	0	0	0	0	36	25	14	—
41-30-8	0	0	0	0	0	0	0	0	0	43	35	46	—
11-13-2	0	4	1	3	0	0	1	0	0	15	4	12	6
17-19-7	2	2	0	0	0	0	1	2	0	14	2	3	8
34-24-4	0	0	0	1	1	0	0	0	–	0	6	3	8
34-25-6	0	0	0	2	0	0	1	1	0	15	11	9	6
34-26-7	0	0	0	0	0	0	–	(8)	–	–	(18)	–	15

A summary of the number of seeds set by each of the different methods of treatment and the difference between the average number of seeds produced by the commercial parent, the F_1, and the F_2 population is given in Table 6.

TABLE 6.—*Comparison of average number of seeds set per head in commercial plants, F_1, and F_2 populations for various treatments involved.*

Treatment	Av. seed per head, 1936			Av. seed per head, 1937		
	Commercial	F_1	Difference	Commercial	F_2	Difference
No treatment	0.2	2.6	+2.4	0.0+	1.5	+1.5
Tripping	0.5	28.5	+28.0	0.2	10.8	+10.6
Rolling	1.2	47.0	+45.8	1.3	18.8	+17.5
Open pollinated	34.7	77.6	+42.9	47.2	25.9	−21.3

Tripping and rolling gave a decided increase in the number of seeds set per head over no treatment in the F_1 and F_2 generations but gave little increase in the commercial, self-sterile parent.

The F_2 plants set more seed per head than the commercial strain in all treatments except the open-pollinated. This increase is undoubtedly due to the self-fertility gene introduced into the progeny by the self-fertile parents. The smaller number of seeds set per head in the open-pollinated F_2 than in the commercial variety may have been due to the fact that the F_2 plants, in general, were less vigorous than the commercial. Many of the F_2 plants showed chlorophyl deficiencies and some of these to such a great extent that they developed only one or two blossoms.

INHERITANCE OF LEAF-MARKING

All of the F_1 plants had crescent marks upon the leaves. The data from the F_2 populations were first analyzed on a family basis, but as there was no significant difference between the segregation in the different F_2 families all of the families were then grouped together. Of the 284 F_2 plants, 210 were classified as having leaf-markings and 74 as being non-marked. This gives a X^2 value of .169 when the observed ratio is compared with a theoretical ratio of 3:1. P falls between .50 and .70 which indicates a good fit. Therefore, it may be concluded that marked and non-marked leaves are differentiated by a single factor.

DATE OF FLOWERING

There was a difference of 19 days between the date of flowering of the commercial variety and the self-fertile inbred line. The commercial variety started blooming July 8 and all 30 plants were in bloom by July 12, whereas the self-fertile inbred line did not blossom until August 1. In the previous year the F_1 plants appeared to be just as early as the commercial variety.

Date of flowering was secured for 261 plants of the F_2 population; 85.1% of the plants flowered earlier than the late parent, although only about 10% flowered as early as the early parent.

DISCUSSION

Breeding red clover by mass selection results in a rather slow rate of improvement since the genetic factors for self-sterility tend to maintain red clover in a heterozygous condition. Inbreeding by sib crosses is a much slower process of attaining homozygosity than by self-fertilization. A further disadvantage in the case of red clover lies in the inability to cross plants possessing the same sterility alleles. Attempts to inbreed without the presence of a self-fertility gene have been handicapped because of inability to secure large populations of selfed plants. Therefore, it would seem desirable to develop a method which through the use of a self-fertility gene permits (a) self pollination, (b) sufficient selfed seed being obtained to permit growing large progenies so that adequate controlled selection can be practiced, (c) maintenance of control of self-sterility genes throughout the inbreeding period, and (d) the elimination of the self-fertility gene when desired to insure seed production by cross pollination in the strain that is selected.

A proposed method to accomplish these objectives is outlined below:

Parental Crosses: 1. Make crosses between selected commercial plants and plants homozygous for the factor for self-fertility, i.e., $S_1S_2 \times S_fS_f$, etc. From this point on only one cross will be followed as others would be handled in a similar manner.

F_1 in the Field: Grow the F_1 and select about eight plants from the cross of commercial $\times$ self-fertile. Cross the selected F_1 plants to a key plant to determine sterility alleles present. Assuming eight F_1 plants, 1–2——8, have been selected, these plants would

be of two genotypes as far as sterility alleles are concerned, i.e., S_1S_f or S_2S_f. Choose one plant as the key plant and cross the other seven plants with it.

2. Self all selected F_1 plants.

F_1 in the Greenhouse: All materials handled in the greenhouse are for the purpose of identification of sterility alleles.

1. Grow and self at least 12 plants from seed obtained from each key cross. If the sterility alleles of the parent plants are different there will be on the average three self-sterile plants out of 12. If the sterility alleles are the same all 12 will be self-fertile.
2. Classify the F_1 plants into two groups on the basis of sterility alleles, i.e., S_1S_f (group 1) or S_2S_f (group 2) as determined under 1.

F_2 in the Field: 1. Plant seed from self-pollinated F_1 plants of the two groups differentiated above. The F_2 plants from group 1 (F_1 genotype S_1S_f) should be S_1S_f and S_fS_f and the F_2 plants from group 2 (F_1 generation S_2S_f) should be S_2S_f and S_fS_f.

2. Self the selected F_2 plants.
3. Cross selected F_2 plants in both group 1 and group 2 with a group of normal self-sterile plants (S_xS_y), i.e. (for group 1):

$$S_xS_y \times S_fS_f = S_1S_x, S_1S_y = \text{self sterile } (50\%)$$
$$S_fS_x, S_fS_y = \text{self fertile } (50\%)$$
$$S_xS_y \times S_fS_f = S_fS_x, S_fS_y = \text{self fertile } (100\%)$$

F_2 in the Greenhouse: 1. Grow and self six plants from each cross of F_2 plants with self-sterile plants. If the genotype of the F_2 parental plant is S_1S_f, 50% of the six will be self-fertile. If the genotype is S_fS_f, all will be self-fertile. If the self-sterile plant used as a tester should happen to contain a sterility allel similar to the one in the F_2 plant being tested ($S_1S_y \times S_1S_f$), all six plants would be self-fertile and the F_2 plant would be classified as a S_fS_f instead of a S_1S_f. However, as the series of sterility alleles in red clover seems to be quite extensive the chances of this occurring are relatively slight and if it did occur it would only mean the loss of one plant as it is the desire to maintain those plants which are heterozygous for self-fertility alleles.

2. On the basis of results obtained from selfing these test crosses all selfed seed obtained from F_2 plants homozygous for S_fS_f will be discarded, using the heterozygous plants S_1S_f as parents for further selection.

F_3 in the Field: As in the previous generation, two groups of F_3 lines will be present, those coming from the F_2 plants S_1S_f and those from the F_2 plants S_2S_f. The genotypes in respect to sterility and fertility genes of these two groups of F_3 families is the same as the genotypes of the two groups of F_2 plants coming from the two original groups of F_1 plants. There are two alternatives which may be followed:

A. The inbreeding program may be continued for the purpose of obtaining relatively homozygous lines to use in producing a synthetic variety and the material handled in the same manner as in the F_2 generation. It probably would be advisable

to test the genotype of plants in only one or two of the best F_3 families.

B. Crosses may be made for the purpose of removing the self-fertility gene and a synthetic variety developed without further selection. This may be accomplished by crossing plants for the S_f gene and necessarily also carrying different sterility alleles. Early blooms on the plants known to come from crosses of F_3 plants of the genotype $S_1S_f \times S_2S_f$ are selfed to determine which are self-sterile (S_1S_2) and then these self-sterile plants may be intercrossed with sterile plants from other series of crosses carried in a parallel manner.

SUMMARY

A self-fertile line of red clover has been isolated at the Minnesota Experiment Station. It appeared in the fifth generation of a self-pollinated line and has continued to be rather highly self-fertile in 10 subsequent generations of self-pollination. This inbred line is homozygous for non-marking of leaf and is much less vigorous than commercial red clover plants.

Seed setting was studied in the F_1 and F_2 generations of crosses between the self-fertile line and commercial red clover. Seed setting was expressed as a percentage of seed produced in rolled and tripped heads in relation to seed setting when open-pollinated. Self-fertility appeared to be dominant in the F_1 generation. Two out of 182 F_2 plants appeared to be definitely self-sterile, 5 gave very low seed production under self-pollination and they may have been pseudo-self-fertile. The remainder evidently carried the factor for self-fertility.

Leaf-marking was dominant in the F_1 over non-marking and segregation in the F_2 was on a 3:1 basis.

The self-fertile line flowered much later than the commercial variety and the F_1 flowered as early as the commercial variety. Approximately 85% of the F_2 plants flowered earlier than the late variety, although the number of factors involved could not be determined.

The suggestion is made and a method outlined for the production of inbred plants carrying different self-sterility alleles and the gene for self-fertility. A plan is also outlined for elimination of the fertility gene after using it as a means of selection in self-pollinated lines.

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THE TOXICITY AND DECOMPOSITION OF SODIUM CHLORATE IN SOILS[1]

ALVIN SCHWENDIMAN[2]

THE increasing use of sodium chlorate for killing noxious perennial weeds makes it desirable that a better understanding be had of those soil and climatic factors responsible for lowering the toxicity and bringing about the decomposition of this chemical. An understanding of these factors will aid in interpreting field results and in planning further experiments.

While two recent papers by Crafts (4, 5)[3] have shown the textural grade and the fertility of soils to be of paramount importance in determining chlorate toxicity, no detailed studies have been made to show the relative importance of soil organic matter, soil moisture, and soil temperature as factors affecting the toxicity and decomposition of chlorates. Since the dissipation of chlorate toxicity in treated soils where leaching is not a factor is apparently dependent upon decomposition alone, factors affecting this process are of primary concern in determining how long treated soils will remain sterile.

Field observations have shown soils high in organic matter to require higher rates of application than soils low in organic matter. Until recently it has been suggested that this effect is the result of the organic matter tending (a) to hasten the decomposition of chlorates either chemically or biologically; (b) to absorb the chlorate, thus rendering it less effective; (c) to increase the water-holding capacity of the soil, thus lowering the concentration in the soil solution; and (d) to cause a more vigorous weed growth which is more difficult to kill.

These theories have been partly discredited as the result of field observations and experimental work. Crafts (5) has shown an inverse relationship between the nitrate content of soils and chlorate toxicity. He believes organic matter may relate to chlorate toxicity more directly through nitrate effects than through decomposition or dilution effects. There is no evidence in the literature that chlorate is fixed in soils in a form unavailable to plants. The manner in which well-decomposed soil organic matter makes increased rates of chlorate application necessary for effective weed control is thus inadequately explained.

Only limited experiments carried on by Aslander (1), Loomis, *et. al* (6), and Bowser and Newton (2) have shown the effects of soil temperature and soil moisture upon the rate of chlorate decomposition. The results of these experiments have shown decomposition

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[3]Numbers in parenthesis refer to "Literature Cited", p. 536.

to be most rapid in moist soils at high temperatures. These workers, however, do not agree as to the rapidity of chlorate decomposition. While Loomis and his co-workers state that decomposition in moist soils at greenhouse temperatures is very rapid, Bowser and Newton suggest that ordinary temperatures have little effect on chlorate decomposition and report that greenhouse temperatures for 18 months failed to decompose it completely in the soil.

Aslander (1) found decomposition to take place in soil saturated with water and considered the reduction to be brought about by micro-organisms under more or less anaerobic conditions. He found species of Penicillium, Aspergillus, and Fusarium able to grow on hay infusions containing a N/10 sodium chlorate solution. The solution was slowly reduced and also found to contain numerous actively growing bacteria.

Bowser and Newton (2) were able to show a very rapid decomposition of chlorate to take place when 10% of alfalfa by weight was added to a sandy loam treated at a rate of 1,308 pounds of sodium chlorate per acre. The rapid reduction of chlorate was considered to be associated with the rapid decomposition of the alfalfa by micro-organisms.

Although the work done by these investigators indicates the possibility of micro-organisms playing a role in the decomposition of chlorates, no conclusive evidence of the ability of any specific micro-organisms to break down chlorates has been presented.

The purpose of the present study was to determine the relative importance of soil organic matter, soil temperature, and soil moisture as factors affecting chlorate toxicity and decomposition and to define as far as possible the nature of their effects.

METHODS AND PROCEDURE

Five soils with definite variations in organic matter were prepared by thoroughly air-drying Miami silt loam and a well-decomposed peat and then mixing them to give three soils varying in organic matter between the two original soils. The soils are designated throughout this paper by Roman numerals, and in most cases the percentage organic matter (abbreviated as O.M.) is also given to characterize the primary difference between the soils. It should be emphasized at this point that the organic matter of the soils used in these experiments was well decomposed and quite resistant to further attack by micro-organisms under normal conditions. This is in sharp contrast to the method used by Bowser and Newton (2) who mixed ground alfalfa with chlorate-treated soils and subsequently found the chlorate to decompose very rapidly.

It is realized that the use of artificial soils prepared in the manner just described has certain objections. Nevertheless, it was felt that the use of various natural soils varying in organic matter would introduce so many more additional and uncontrollable variables besides organic matter that the former method was chosen.

The method used to study the toxicity and decomposition of sodium chlorate was similar to that of Crafts (3). Individual soil cultures consisted of the soils placed in No. 2 tin-plate cans. The following air-dry weights of the respective soils (with the organic matter and soil pH indicated) were used per can: Soil I

(peat, 70.6% O.M., pH 7.2), 200 grams; soil II (34.2% O.M., pH 7.0), 325 grams; soil III (18.0% O.M., pH 6.5), 425 grams; soil IV (9.6% O.M., pH 6.2), 500 grams; and soil V (Miami silt loam, 4.4% O.M., pH 5.8), 550 grams. The weights of the air-dry soils used per culture decreased with an increase in organic matter because of the greater swelling of the more highly organic soils upon wetting.

Three replicates were used for every individual soil treatment. One series of cultures was used to study the effect of high temperatures (year-round greenhouse temperatures, 70–110° F) and low temperatures (cultures kept outside the greenhouse during winter and in cold storage during summer, 0–40° F) at a moisture level optimum for plant growth.

A second series was used to study the effect of four moisture levels at year-round greenhouse temperatures. These moisture levels are designated as high, medium, low, and alternate. The medium level was the percentage moisture in each soil on an air-dry basis sufficient for optimum plant growth. The high level contained 50% more moisture per culture than the medium level, while the low level contained 50% less moisture than the medium level. The soils of the alternate level were brought to the medium moisture level every two to three weeks after the soil had been allowed to air-dry thoroughly.

The soils of the temperature series received seven rates of chlorate application and those of the moisture series three rates. These are expressed as milligrams of sodium chlorate per culture and are given in Tables 1 and 3 for the temperature and moisture series, respectively. Expressed as pounds per square rod based on the surface area of the individual cultures, these rates are as follows: 0.30, 0.60, 1.50, 2.40, 3.30, 4.20, and 5.10.

To obtain a biological indication of chlorate toxicity and decomposition, 18 State Pride C. I. 1154[4] oat seeds were planted per culture and the plants thinned to 14 at the end of one week. The green weight of oats produced on the soils three weeks from the date of planting was taken as the criterion of toxicity. All oat growth was returned to the respective soil cultures and allowed to decompose before replanting. Only three oat croppings were taken on the temperature series in a period of 15 months. A single oat cropping was taken on the moisture series after the cultures had been maintained at the various moisture levels for one year. The cultures of the moisture series and those of the temperature series kept at high temperatures remained in the greenhouse throughout the experimental period. Those cultures kept at low temperatures were brought into the greenhouse only when an oat cropping was taken. As no leaching of chlorate from the cultures was possible, any increased growth of oats with time and cropping was considered the result of chlorate decomposition.

To obtain further evidence that the loss in toxicity with time, as evidenced by increased oat growth, was the result of actual decomposition and not other factors, such as possible fixation or absorption in a form less available to plants, the percentage decomposition for both the temperature and moisture series was determined chemically at the end of the experimental period just prior to the final cropping of oats. A method for the determination of chlorates in soil extracts recently proposed by Rosenfels (8) was used. Both the chlorate present in the soil extracts and the increase in chloride content of the extracts of treated soils over the extracts of untreated soils was determined. This was done in order to report the percentage recovery of the sodium chlorate either as sodium chloride (decomposed) and/or sodium chlorate (undecomposed). A composite sample of

[4]Accession number of the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture.

soil was taken from the three replicates of a given treatment and determinations made on duplicate aliquots of the single soil extract.

To establish any possible relationship between the ability of the soils of the moisture series to decompose hydrogen peroxide and the percentage chlorate decomposed, the catalytic activity of these soils was determined after they had been maintained at the four moisture levels for one year. The catalytic activity was compared on the basis of the number of minutes required to evolve 50 cc of oxygen when 6 grams of thoroughly air-dried soil were wet with 30 cc of distilled water and treated with 10 cc of 3% neutralized hydrogen peroxide. A further description of the method and apparatus used in making the catalytic determination is given by Schwendiman (9).

EXPERIMENTAL RESULTS

EFFECT OF ORGANIC MATTER UPON CHLORATE TOXICITY

Table 1 and Figs. 1 and 2 show clearly that with an increase in general soil fertility and organic matter, chlorate toxicity is markedly

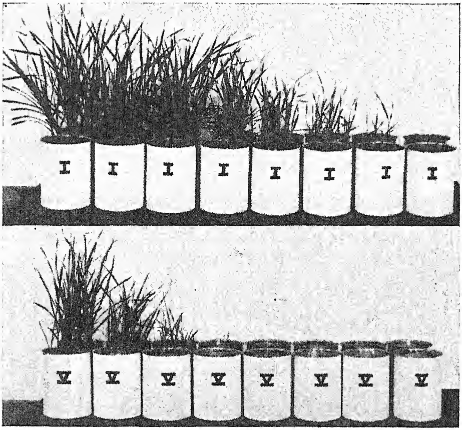


FIG. 1.—Relation of chlorate toxicity to soil organic matter as shown by the growth of oats on soils I (70.6% O.M.) and V (4.4% O.M.). From left to right both soils received the following number of mg of sodium chlorate per culture: 0, 28, 56, 140, 224, 308, 392, and 476.

lowered. That the soil fertility increases with the organic matter is evident from the growth of oats on the untreated soils. Reference to Table 1 shows that for the first oat cropping an application of 56 mg

TABLE 1.—*The growth of oats at three dates as an indicator of the toxicity and decomposition of sodium chlorate in soils maintained at optimum moisture levels and at low (A) and high (B) temperatures for one year.*

Soil No. and organic matter, %	Mg. $NaClO_3$ per culture	P.p.m. of $NaClO_3$ in soil on air-dry basis	P.p.m. of $NaClO_3$ in soil solution	Dates of cuttings and grams of green top growth of oats three weeks after planting: Oct. 15, 1938*		Apr. 8, 1939		Dec. 23, 1939	
				A	B	A	B	A	B
	None	None	None	5.26	5.05	6.52	6.89	4.34	4.13
	28	138	153	4.39	3.97	6.40	6.48	4.47	4.18
	56	275	306	4.19	3.88	5.83	5.44	4.13	4.19
I	140	688	765	2.40	2.11	3.01	2.96	3.51	4.30
	224	1,100	1,224	0.97	1.18	1.64	2.26	2.30	3.92
70.6%	308	1,513	1,683	0.64	0.61	1.05	1.15	1.77	3.39
	392	1,925	2,142	0.34	0.24	0.67	0.69	1.05	2.68
O.M.	476	2,338	2,601	0.09	0.11	0.35	0.50	0.66	2.47
	None	None	None	4.53	4.61	5.70	6.08	4.56	4.11
	28	85	172	3.78	3.62	4.69	5.67	4.74	4.24
	56	170	344	3.05	3.11	4.18	4.94	4.11	4.05
II	140	422	860	1.41	1.43	2.21	2.95	3.03	3.81
	224	676	1,376	0.52	0.34	1.04	1.30	1.77	3.55
32.4%	308	930	1,892	0.19	0.12	0.60	0.80	1.29	3.42
	392	1,183	2,408	0.07	0.10	0.42	0.49	0.67	2.70
O.M.	476	1,437	2,924	0.04	0.06	0.32	0.33	0.56	2.03
	None	None	None	4.97	5.21	5.15	5.92	4.09	3.61
	28	65	190	3.46	3.52	5.49	5.35	3.91	3.69
	56	130	380	1.69	1.37	2.34	2.82	3.08	3.57
III	140	322	955	0.71	0.62	1.85	2.35	2.84	3.60
	224	516	1,520	0.12	0.14	0.89	1.09	1.54	3.15
18.0%	308	710	2,090	0.03	0.04	0.45	0.56	0.99	2.65
	392	903	2,660	0.03	0.04	0.22	0.31	0.50	1.82
O.M.	476	1,096	3,230	0.02	0.07	0.13	0.23	0.35	1.21
	None	None	None	4.92	4.77	4.72	4.95	3.78	3.48
	28	55	204	3.10	3.23	4.88	5.52	3.70	3.43
	56	110	408	1.12	1.01	4.27	4.20	3.65	3.41
IV	140	275	1,020	0.18	0.17	1.68	1.94	2.42	3.35
	224	440	1,632	0.05	0.06	0.73	0.76	1.23	3.16
9.6%	308	605	2,244	0.03	0.03	0.37	0.35	0.87	2.14
	392	770	2,856	0.04	0.03	0.15	0.24	0.41	1.56
O.M.	476	935	3,468	0.03	0.02	0.13	0.19	0.34	1.08
	None	None	None	3.77	3.47	2.97	3.42	3.59	3.16
	28	50	250	1.79	1.69	3.87	4.25	3.24	3.43
	56	100	500	0.54	0.44	3.03	3.17	3.32	3.50
V	140	250	1,250	0.07	0.07	0.62	0.87	2.07	2.74
	224	400	2,000	0.03	0.06	0.38	0.21	1.22	2.56
4.4%	308	550	2,750	0.03	0.04	0.16	0.17	0.55	1.66
	392	700	3,500	0.04	0.03	0.10	0.09	0.40	0.99
O.M.	476	850	4,250	0.03	0.03	0.10	0.06	0.15	0.70

*The green weights of this date indicate the initial toxicity without any previous temperature difference between A and B.

of sodium chlorate per culture to soil V (4.4% O.M.) was as effective in limiting oat growth to approximately 0.5 gram as was 308 mg per culture to soil I (70.6% O.M.).

To determine whether this immediate lowering of toxicity might have been caused by rapid fixation or decomposition, duplicate soil cultures were similarly treated, allowed to stand for three weeks, and extracted with distilled water. All chlorate was readily recovered in an undecomposed condition. It is apparent that organic matter does not lower chlorate toxicity by either fixation or rapid decomposition.

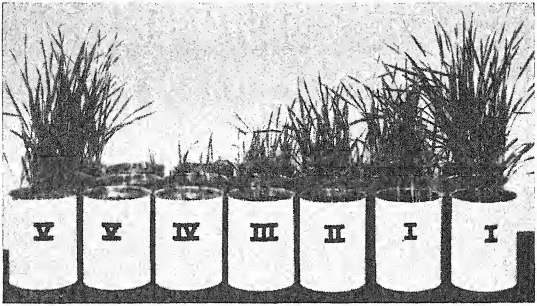
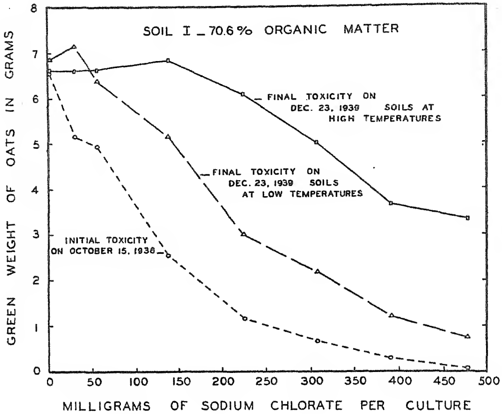


FIG. 2.—Relation of chlorate toxicity to soil organic matter as shown by the growth of oats on soils I (70.6% O.M.), II (34.2% O.M.), III (18.0% O.M.), IV (9.6% O.M.), and V (4.4% O.M.). With the exception of the untreated controls on either extreme, all cultures received 140 mg of sodium chlorate.

EFFECT OF SOIL TEMPERATURES UPON CHLORATE DECOMPOSITION

A biological indication of the extent to which high and low soil temperatures affect chlorate decomposition is given in Table 1 for all soils and represented graphically for soils I (70.6% O.M.) and V (4.4% O.M.) in Fig. 3. The graphs of this figure were made by correcting the green weights of the oats as given in Table 1 for date effects on the basis of the untreated checks of the April, 1939, cropping as 100%. With the exception of the two lowest rates of application, the growth of oats indicates that definitely more chlorate was decomposed at the higher temperatures.

Table 2 gives the percentage decomposition for soils I, III, and V as determined for three of the seven rates of application. It is evident that decomposition has been greatest in the soils maintained at high temperatures irrespective of organic matter. The data show clearly that the well-decomposed organic matter of these soils has not been a factor in determining the rate of chlorate decomposition. Good agreement is shown between the growth of oats and the percentage decomposition.



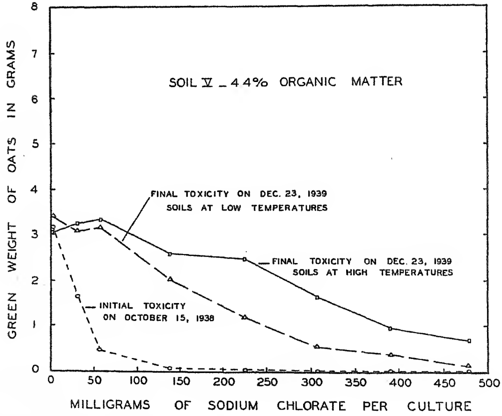


FIG. 3.—The decomposition of sodium chlorate in soils I and V as affected by high (70°–110° F) and low (0–40° F) temperatures and optimum moisture levels maintained in the soils for one year and as indicated by the growth of oats at two dates.

TABLE 2.—*The percentage decomposition of sodium chlorate in soils maintained at optimum moisture levels and at low (A) and high (B) temperatures for one year.*

Mg. of sodium chlorate added per culture in Sept., 1938	Percentage decomposition as determined in Nov., 1939							
	Soil I 70.6% O. M.		Soil III 18.0% O. M.		Soil V 4.4% O. M.		Averages for soils I, III, and V	
	A	B	A	B	A	B	A	B
56	65	100	62	83	79	92	69	92
224	43	82	39	77	59	80	47	83
392	30	58	29	56	45	58	35	57
Averages.........	46	80	43	72	61	77	50	77
% recovery*........	101	103	100	100	92	92	—	—

*Average percentage recovery of sodium chlorate as sodium chloride (decomposed) and/or sodium chlorate (undecomposed).

An analysis of variance made on the green weights of the oats of the temperature series as given in Table 1 showed the effect of the soils, the chlorate applications, the temperature levels, and the dates of cropping all to be significant. Because of the non-homogeneous variation of the green weights, the analysis was made only on the green weights of the untreated cultures and the first three rates of application.

EFFECT OF SOIL MOISTURE LEVELS UPON CHLORATE DECOMPOSITION

A biological indication of the extent to which the high, medium, low, and alternate moisture levels affected chlorate decomposition is given in Table 3. The p.p.m. of sodium chlorate in the soil solutions at the various moisture levels indicate only the extent of chlorate dilution during the maintenance of the moisture levels from October, 1938, to October, 1939. Between the latter date and January 1940 the soils were thoroughly air-dried and samples were taken to determine chlorate decomposition and catalytic activity. All soils were maintained at the medium or optimum moisture level while the oats were grown.

The growth of oats indicates increased decomposition with increased moisture levels. This can be seen by comparing the initial toxicity as given by the green weight of oats in column 4 of Table 3 with the green weights of the oats at the various moisture levels. At the lowest rate of application it would appear from the green weight of oats that practically all chlorate had decomposed. Reference to Table 4 shows that this is largely true. The growth of oats would also seem to indicate that decomposition had been just as great at the alternate moisture level as at the low moisture level in spite of the fact that the former received much less moisture than the latter. These same conclusions regarding the effect of the low and alternate moisture levels are borne out in Table 4 which shows the decomposi-

TABLE 3.—*The growth of oats at two dates as an indicator of the toxicity and decomposition of sodium chlorate in soils treated with sodium chlorate and subsequently maintained at four moisture levels and at high temperatures (70°–110° F) for one year.**

Soil No. and organic matter, %	Mg $NaClO_3$ per culture	P.p.m. of $NaClO_3$ in soil on air-dry basis	Initial toxicity Oct., 1938, green weight in grams†	Oat cutting of Jan. 6, 1940, on soils previously maintained at four moisture levels and at high temperatures for one year and which had concentrations of sodium chlorate in Oct., 1938, as indicated							
				High moisture		Medium moisture		Low moisture		Alternate moisture	
				$NaClO_3$, p.p.m. in soil solution	Green weight in grams	$NaClO_3$, p.p.m. in soil solution	Green weight in grams	$NaClO_3$, p.p.m. in soil solution	Green weight in grams	$NaClO_3$, p.p.m. in soil solution‡	Green weight in grams
I 70.6% O. M.	None	None	4.23	None	4.34	None	4.10	None	4.54	None	4.09
	56	275	3.47	204	4.49	306	4.09	612	4.54	306	4.15
	224	1,100	1.04	816	4.17	1,224	3.14	2,448	3.11	1,224	3.35
	392	1,925	0.28	1,428	3.11	2,142	2.39	4,284	1.42	2,142	1.84
II 34.2% O.M.	None	None	3.98	None	4.09	None	3.89	None	3.95	None	4.00
	56	170	2.81	229	3.97	344	3.87	688	3.67	344	3.97
	224	676	0.42	917	3.49	1,376	2.88	2,752	2.34	1,376	2.63
	392	1,183	0.08	1,605	2.55	2,408	1.77	4,816	0.88	2,408	0.92
III 18.0% O.M.	None	None	4.02	None	4.20	None	3.77	None	4.17	None	4.00
	56	130	1.43	257	3.95	380	3.79	760	3.84	380	3.99
	224	516	0.13	1,013	3.93	1,520	3.23	3,040	1.69	1,520	1.96
	392	903	0.05	1,773	3.35	2,660	2.33	5,320	0.83	2,660	0.82
IV 9.6% O.M.	None	None	3.69	None	3.68	None	3.39	None	3.59	None	4.05
	56	110	1.00	272	3.59	408	3.63	816	3.54	408	3.86
	224	440	0.05	1,088	3.63	1,632	2.90	3,264	1.44	1,632	1.48
	392	770	0.04	1,904	3.32	2,856	2.07	5,712	0.31	2,856	0.49
V 4.4% O.M.	None	None	3.50	None	3.23	None	3.62	None	3.71	None	3.45
	56	100	0.48	334	3.18	500	3.60	1,000	3.51	500	3.51
	224	400	0.05	1,340	3.49	2,000	3.43	4,000	1.16	2,000	1.03
	392	700	0.04	2,338	3.15	3,500	2.71	7,000	0.25	3,500	0.13

*Minimum significant difference at the 5% point for green weights within and between soils, 0.37 grams.
†Corrected green weights of the correspondingly treated soils of the temperature series.
‡These concentrations in the soil solution only when brought to the medium moisture level before allowing the soils to dry out.

tion at the alternate moisture level to be higher in every case than at the low level.

TABLE 4.—*The percentage decomposition of sodium chlorate in soils maintained at four moisture levels and at high temperatures (70°–110° F) for one year.*

Soil No. and organic matter, %	Moisture levels	Percentage decomposition as determined in Nov., 1939			
		Mg. of sodium chlorate added per culture in Sept., 1938			Averages for moisture levels
		56	224	392	
I	High	100	90	77	89
	Medium	97	63	50	70
70.6%	Low	96	43	33	57
O.M.	Alternate	97	58	46	67
% recovery*	....	103	104	108	—
III	High	100	92	80	91
	Medium	87	64	47	66
18.0%	Low	78	47	32	52
O.M.	Alternate	79	50	35	55
% recovery*	....	109	99	99	—
V	High	100	98	89	95
	Medium	89	89	84	87
4.4%	Low	68	51	36	52
O.M.	Alternate	80	66	53	66
% recovery*	....	111	92	95	—
Averages	High	100	93	82	92
for soils	Medium	91	72	60	74
I, III,	Low	81	47	34	54
and V	Alternate	85	58	45	63

*Average percentage recovery of sodium chlorate as sodium chloride (decomposed) and/or sodium chlorate (undecomposed).

There appears to be little, if any, effect of organic matter upon the rate of decomposition. The effect of the various moisture levels is of far greater importance.

An analysis of variance made on the green oat weights of the moisture series showed the effect of the soils, the chlorate applications, and the moisture levels all to be significant.

RELATION OF SOIL CATALYTIC ACTIVITY TO CHLORATE DECOMPOSITION

Table 5 gives the catalytic activity of all soils of the moisture series. The values given in minutes are the averages of three replicates. It should be kept in mind that low values indicate high activity since a smaller number of minutes was required to evolve 50 cc of oxygen. The effect of the various moisture levels is most marked in the case of soil V and least marked in soil I. In general it is evident that the catalytic activity is decreased (number of minutes increased)

as the moisture levels decrease. This effect is least marked in the untreated soils and becomes more evident as the rate of chlorate application is increased.

TABLE 5.—*The catalytic activity of soils treated with sodium chlorate and subsequently maintained at four moisture levels and at high temperatures (70°–110° F) for one year.*

Soil No. and organic matter, %	Moisture levels	Catalytic activity indicated as number of minutes required to evolve 50cc of oxygen				
		Milligrams of $NaClO_3$ per culture				Average number of minutes
		None	56	224	392	
I 70.6% O.M.	High	7.07	7.31	8.28	9.50	8.04
	Medium	8.34	9.03	12.59	14.08	11.01
	Low	6.94	8.00	11.72	13.29	10.00
	Alternate	7.49	8.78	10.72	13.94	10.23
II 34.2% O.M.	High	9.92	10.87	12.17	12.78	11.43
	Medium	10.28	10.71	13.66	14.24	12.22
	Low	9.62	11.34	14.32	15.05	12.58
	Alternate	10.58	11.27	14.73	16.49	13.27
III 18.0% O.M.	High	6.57	7.06	7.35	8.77	7.44
	Medium	10.20	11.03	11.96	12.73	11.48
	Low	10.24	11.76	13.27	14.84	12.53
	Alternate	11.26	12.28	13.48	15.25	13.07
IV 9.6% O.M.	High	4.29	4.86	5.23	5.72	5.02
	Medium	8.74	8.97	9.37	10.12	9.31
	Low	8.70	10.59	11.64	13.23	11.04
	Alternate	11.31	14.45	15.89	16.38	14.51
V 4.4% O.M.	High	4.14	4.38	6.13	7.05	5.42
	Medium	7.04	6.82	8.56	9.16	7.90
	Low	6.87	9.90	10.05	11.17	9.50
	Alternate	9.27	14.98	15.47	15.60	13.83
Averages for all soils	High	6.40	6.90	7.83	8.76	7.47
	Medium	8.92	9.31	11.23	12.07	10.38
	Low	8.47	10.32	12.20	13.52	11.13
	Alternate	9.98	12.35	14.06	15.53	12.98

Minimum significant differences at the 5% point:
Between and within each soil at each chlorate and at each moisture treatment.......... 1.17 min.
Between and within each soil at each moisture treatment.......... 0.58 min.
Between chlorate-moisture means for all soils.......... 0.52 min.
Between moisture means for all soils.......... 0.26 min.

It appears that there is no relationship between the catalytic activity and the organic matter content of the soils. By heating samples of the peat (soil I, 70.6% O.M.) and Miami silt loam (soil V, 4.4% O.M.) at 100° C for 48 hours, the reduction in catalytic activity for the two soils was 84 and 40%, respectively. This indicates a predominance of organic catalysts in the peat and a predominance of inorganic catalysts in Miami silt loam and explains the lack of any relationship between the catalytic activity and organic matter content of the soils.

A comparison of Tables 4 and 5 shows that for soils I, III, and V at the high, medium, and low moisture levels, the percentage decomposition decreases with a decrease in the catalytic activity corresponding to a lowering of the moisture level. In general, this observation applies to all five soils, but the relationship becomes less marked as the organic matter increases. This general relationship for the average values of soils I, III, and V is shown graphically in Fig. 4. A study of this figure and further comparison of the average values of catalytic

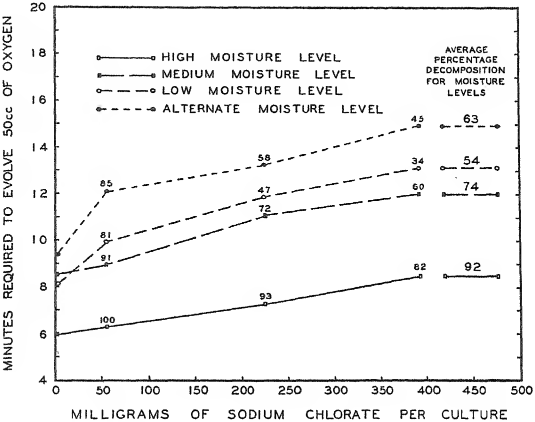


FIG. 4.—The relation of catalytic activity to chlorate decomposition in soils I (70.6% O.M.), III (18.0% O.M.), and V (4.4% O.M.) as affected by four moisture levels and three rates of chlorate application. All values are the averages for the three soils. The figures superimposed on the curves are the average percentages of decomposition.

activity and chlorate decomposition for all soils at the high, medium, and low moisture levels, as given in Tables 4 and 5, bears out a general positive relationship between the catalytic activity and chlorate decomposition at the specified moisture levels. At the alternate moisture level this relationship does not hold. This is plainly evident in Fig. 4 where it can be seen that at the alternate level the percentage decomposition is higher than at the low moisture level in spite of a much lower catalytic activity for the alternate level. Since the soils of the alternate level were moistened only every two to three weeks, depending upon the rate at which they were dried out, these soils received actually less moisture than the soils of the low moisture level. If a lowering of the catalytic activity is to be attributed to a decrease

in moisture, the catalytic activity at the alternate level is as would be expected. In this case, and on the basis of an assumed positive relationship between catalytic activity and chlorate decomposition for the other moisture levels, it would appear that the greater portion of the decomposition at the alternate level would have to be attributed to some factor or factors coming into play during the wetting and drying of the soil and which factor or factors are not associated with a change in catalytic activity as influenced by various moisture levels.

DISCUSSION

It has been shown that the effect of organic matter in lowering chlorate toxicity is immediate and not dependent upon a time factor. Rapid decomposition brought about by well-decomposed matter cannot be a factor in lowering the toxicity since the percentage decomposition in all soils was practically the same for a given set of conditions irrespective of the organic matter. Complete recovery of all chlorate added to soil I (70.6% O.M.) was obtained at all times using only distilled water. This disposes of the theories that organic matter lowers chlorate toxicity by absorbing the chlorate in a form less available to plants or by bringing about its rapid decomposition.

Table 1 shows that as the organic matter of the soils increases the greater water-holding capacity results in a dilution of the chlorate in the soil solution. Although this dilution effect is believed to be a partial explanation of how organic matter lowers chlorate toxicity, it is evident that some other factor is of much greater importance. If the dilution effect alone were involved, a much lower differential in toxicity between the soils would be expected than was actually found.

Although determinations of the nitrate content of the soils used in these experiments were not made, it seems apparent that organic matter is related to chlorate toxicity more directly through nitrate effects as described by Crafts (5) than through other postulated effects. The effect of organic matter in lowering chlorate toxicity is thus attributed largely to the higher nitrate content inhibiting the uptake of chlorate ions by plants.

The rate of decomposition in general appears to have been unaffected by varying amounts of well-decomposed organic matter. Since the effect of moisture upon decomposition is so marked, occasional differences between soils may well have been caused by moisture conditions not exactly comparable rather than by differences in organic matter. With respect to an interpretation of chlorate decomposition in soils, it is interesting that the rate of decomposition should not have shown some relationship to the greatly varying organic matter content. The rate of decomposition was found to be roughly proportional to the organic matter only when the treated soils were autoclaved or when conditions of complete saturation were maintained for one to two weeks. A discussion of the nature of chlorate decomposition under these conditions is given elsewhere by the author (9).

The only basis for interpreting the nature of the decomposition of sodium chlorate in the soils used in these experiments is the per-

centage decomposition at the various moisture levels as related to the catalytic activity of the same soils. Waksman and Dubos (10) have pointed out that the liberation of oxygen from hydrogen peroxide by soils is the result of (a) the action of the enzyme catalase, which may be of either plant or microbial origin, the latter usually predominating; (b) the action of other unidentified organic substances; and (c) the action of inorganic catalysts. With variations in the moisture levels it is more probable that the catalytic activity of a soil would change to a greater extent by variation in the amount of the enzyme catalase than by changes in the activity of any inorganic catalysts. Since the soils used for the catalytic determinations were maintained for one year at the four moisture levels without the incorporation of any new plant residue, an increase in catalytic activity with increased moisture would seem to be the result of greater numbers of micro-organisms. The logical interpretation, then, of the relationship between the percentage decomposition, the catalytic activity, and the moisture levels would be that the decomposition of chlorates in soils is largely brought about by the activities of micro-organisms. Temperature and moisture influence the rate of decomposition indirectly by accelerating or retarding the activities of soil micro-organisms.

The greater decomposition at the alternate moisture level than at the low moisture level is attributed to some factor or factors coming into play during the wetting and drying process. Whatever the nature of these factors, it is more probable that they are chemical or physical rather than biological since with the extremely low moisture content it is very questionable that the decomposition could have been the result of the activities of micro-organisms. Since the catalytic activity at the alternate moisture level was the lowest, this also indicates that there had been the least activity of micro-organisms at this level. Under more intense conditions of drying and wetting such as takes place in fields during the summer, this observation may account for considerable chlorate decomposition in the relatively dry surface soil.

The extent to which variations in the pH of the soils may have influenced the rate of decomposition was not determined. Since there is some evidence in the literature (7, 11) that low pH values hasten chlorate decomposition, the occasional greater decomposition in soil V (4.4% O.M., pH 5.8) than in soil I (70.6% O.M., pH 7.2) may possibly be attributed to the lower pH value.

The possible application of these findings to field studies and eventual field practices in the use of chlorates remains to be seen. Studies are needed to determine to what extent they may hold true in the field.

SUMMARY

The relative importance of soil organic matter, soil temperature, and soil moisture as factors affecting chlorate toxicity and decomposition has been studied and the nature of the effects of these factors partially defined. The results and conclusions are summarized as follows:

in moisture, the catalytic activity at the alternate level is as would be expected. In this case, and on the basis of an assumed positive relationship between catalytic activity and chlorate decomposition for the other moisture levels, it would appear that the greater portion of the decomposition at the alternate level would have to be attributed to some factor or factors coming into play during the wetting and drying of the soil and which factor or factors are not associated with a change in catalytic activity as influenced by various moisture levels.

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Although determinations of the nitrate content of the soils used in these experiments were not made, it seems apparent that organic matter is related to chlorate toxicity more directly through nitrate effects as described by Crafts (5) than through other postulated effects. The effect of organic matter in lowering chlorate toxicity is thus attributed largely to the higher nitrate content inhibiting the uptake of chlorate ions by plants.

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The only basis for interpreting the nature of the decomposition of sodium chlorate in the soils used in these experiments is the per-

centage decomposition at the various moisture levels as related to the catalytic activity of the same soils. Waksman and Dubos (10) have pointed out that the liberation of oxygen from hydrogen peroxide by soils is the result of (a) the action of the enzyme catalase, which may be of either plant or microbial origin, the latter usually predominating; (b) the action of other unidentified organic substances; and (c) the action of inorganic catalysts. With variations in the moisture levels it is more probable that the catalytic activity of a soil would change to a greater extent by variation in the amount of the enzyme catalase than by changes in the activity of any inorganic catalysts. Since the soils used for the catalytic determinations were maintained for one year at the four moisture levels without the incorporation of any new plant residue, an increase in catalytic activity with increased moisture would seem to be the result of greater numbers of micro-organisms. The logical interpretation, then, of the relationship between the percentage decomposition, the catalytic activity, and the moisture levels would be that the decomposition of chlorates in soils is largely brought about by the activities of micro-organisms. Temperature and moisture influence the rate of decomposition indirectly by accelerating or retarding the activities of soil micro-organisms.

The greater decomposition at the alternate moisture level than at the low moisture level is attributed to some factor or factors coming into play during the wetting and drying process. Whatever the nature of these factors, it is more probable that they are chemical or physical rather than biological since with the extremely low moisture content it is very questionable that the decomposition could have been the result of the activities of micro-organisms. Since the catalytic activity at the alternate moisture level was the lowest, this also indicates that there had been the least activity of micro-organisms at this level. Under more intense conditions of drying and wetting such as takes place in fields during the summer, this observation may account for considerable chlorate decomposition in the relatively dry surface soil.

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The possible application of these findings to field studies and eventual field practices in the use of chlorates remains to be seen. Studies are needed to determine to what extent they may hold true in the field.

SUMMARY

The relative importance of soil organic matter, soil temperature, and soil moisture as factors affecting chlorate toxicity and decomposition has been studied and the nature of the effects of these factors partially defined. The results and conclusions are summarized as follows:

1. Chlorate toxicity in five soils was decreased markedly by organic matter increments of 4.4, 9.6, 18.0, 34.2, and 70.6%. This effect of organic matter in lowering toxicity is attributed primarily to increments in the nitrate content. Nitrates have been shown by other workers to inhibit the uptake of chlorate ions by plants.
2. The diluting effect of organic matter upon the chlorate in the soil solution which results from an increased moisture-holding capacity is of minor importance in lowering toxicity.
3. Neither rapid chlorate decomposition nor chlorate fixation by well-decomposed organic matter are responsible for lowering the toxicity.
4. Chlorate decomposition in soils is greatly accelerated by high temperature levels in combination with high moisture levels. The rate of decomposition at high temperatures is limited by the moisture level and *vice versa*.
5. Varying amounts of well-decomposed organic matter under temperature and moisture conditions normally occurring in soils do not affect the rate of chlorate decomposition. The rate of decomposition was roughly proportional to the amount of organic matter only under conditions of sustained complete soil saturation or when the treated soils were autoclaved.
6. Increments in the moisture content of soils to a point below the saturation level results in an increased power of the soils to decompose hydrogen peroxide. Associated with this increase in the catalytic power there is a general positive relationship of greater chlorate decomposition. The increments in moisture are believed to accelerate the activities of micro-organisms which are then responsible for the greater catalytic activity and the corresponding increase in chlorate decomposition.
7. Under conditions of relatively low moisture and alternate wetting and drying of the soil, the positive relationship between the catalytic activity and chlorate decomposition does not hold. In this case the decomposition of chlorate is attributed to chemical and physical factors coming into play during the wetting and drying of the soils.
8. The effect of organic matter in lowering chlorate toxicity is immediate. For this reason it is very unlikely that a rapid lowering of chlorate toxicity by decomposition will ever be of as much importance as the effect of large amounts of organic matter.
9. In determining the rate of chlorate decomposition under normal soil conditions, soil temperature and soil moisture are of about equal importance and each is of much greater importance than the effect of large amounts of well-decomposed organic matter.

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CONTROLLED SELF- AND CROSS-POLLINATION OF *TRIFOLIUM REPENS*[1]

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THE difficulties encountered in making reliable controlled self- and cross-pollinations are limiting factors in breeding and genetic studies with many species. Several investigators have made successful self- and cross-pollinations with white clover, but only Williams (4)[3] has published his technics in detail. In the course of breeding and genetic studies with white clover since 1937 there have been developed several pollination technics which are relatively simple to execute and which yield reasonably precise results.

GREENHOUSE TECHNICS

Nearly all controlled cross-pollinations have been made during the winters in screened greenhouses, using plants which had been propagated vegetatively. Flowering was induced by raising the night temperature to 70° F and by lighting at night to extend the "day" to 18 hours, using Mazda bulbs to provide 75 to 150 foot-candles at the pot surface.[4] The first florets opened within 5 to 6 weeks after supplementary lighting began.

The emasculating technic was an adaptation of the suction method described by Kirk (3) for use with sweet clover. An electrically-driven suction pump provided negative pressure through capillary glass nozzles. The flower heads handled most easily in crossing were those on which about three-fourths of the florets had opened, but, for convenience, only 10 of the most recently opened florets were used in any cross. Pollen for crossing was obtained by tripping a floret onto fine emery paper which had been glued onto the broad end of a toothpick.

Since the anthers extended above the stigma in most flowers, removal of the anthers was necessary to make it easy to see that abundant pollen had been placed on the stigma. In no case were any seeds produced when florets were emasculated but not pollinated. To determine whether emasculation was necessary to prevent self-fertilization when crossing, six plants with different degrees of pseudo-self-compatibility, all with recessive solid-green leaves, were crossed as females in three ways with a plant homozygous for a dominant white leaf marking, *viz.*, (a) emasculated first, as described above; (b) tripped first with a toothpick, other than the one used for pollinating; and (c) pollinated directly without previous emasculation or tripping. Nearly the same number of seeds per head were obtained by all three methods, but they involved different amounts of work.

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[3]Figures in parenthesis refer to "Literature Cited", page 545.

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The first was probably the easiest because here it was simple to apply the pollen. The second involved almost the same number of operations as the first, but required more care in pollination. The third was definitely more time-consuming since it required several strokes of the toothpick with frequent cleanings in between for each flower crossed, and required a much larger amount of pollen to be certain of adequate pollination. Out of 557 seedlings grown from treatment (a), only three (0.5%) were solid green. No green seedlings were found among the 214 and 260 grown from treatments (b) and (c), respectively.

For most purposes it appears that cross-pollinations could be made without previous emasculation even when using pseudo-self-compatible plants. For large-scale studies of cross-compatibility, however, where time and pollen are limiting factors and where the results are measured in seed-set, or for genetic studies where no markers are available, emasculation is considered worthwhile solely because it facilitates pollination.

Selfing was attempted in the greenhouse with (a) 10 emasculated flowers, (b) 10 unemasculated flowers, (c) 10 flowers emasculated in the bud, and (d) entire heads rubbed every other day throughout the duration of flowering. Most of the plants that have been selfed by these methods set seed only when rubbed, but some plants have been found which are apparently highly self-compatible in both field and greenhouse under all types of pollination. This latter type of self-compatibility is heritable and its behavior is being studied (2).

BEE POLLINATION IN THE FIELD

Cages 4 × 4 × 8 feet covered with 12-mesh window screen were set up in the field to cover two spaced plants, but sometimes it was possible to include a third in the alley between the two. Second-summer plants were caged when they had begun to flower in late May or early June. Two frames of emerging brood, to which adult bees were clinging, were put into a four-frame swarm box, together with two frames of foundation and a queen. The hive's opening was placed against a small hole cut in the bottom board of the cage so that the bees could fly only inside the cage. The bees were left in the cage 5 to 6 weeks and the first seed harvest was taken off shortly after the bees were removed. While the bees were confined, a standard sugar syrup was provided from a feeding can through a small hole in the inner cover of the hive, and a jar of water was provided inside the cage. The old bees spent most of their time flying against the top of the cage, but the young bees began almost at once to visit all the flowers in the cage.

Good pollination was effected as shown by the number of seeds obtained in compatible crosses or in selfing the highly self-compatible plant (Tables 1 and 2). Since some lodging of heads occurred within the cage, the 25 cleanest and fullest heads from each plant were picked out first at threshing and the number of flowers and seeds counted. The total seeds were also counted for all heads harvested.

In 1939 there were on the average about the same number of

TABLE 1.—*Seed-set with cross-pollination under bee cages (first harvest).*

Compatibility relationship	Cage No.	Year caged	Plant No.	25 "best" heads: Flowers per head, av.	25 "best" heads: Seeds per head, av.	All heads: Total No.	All heads: Seeds per head, av.
			1-series				
Compatible Cross	I	1939	1-5*	44.6	21.2	346	8.3
			1-6	56.2	42.9	325	22.1
	II	1939	1-8	49.4	49.1	320	17.3
			1-9	40.6	26.6	91	17.9
			1-13	62.3	31.9	230	15.3
	III	1940	1-14	56.7	46.1	863	21.1
			1-15*	48.3	49.2	985	20.3
	Av. and total			51.1	38.1	3,160	18.6
Incompatible Cross	IV	1939	1-10	48.5	0.40	123	0.33
			1-11	53.0	0.16	77	0.45
			1-15*	45.4	0.64	111	0.49
	V	1940	1-4	43.4	0.40	445	0.29
			1-5*	39.7	0.24	386	0.14
	Av. and total			46.0	0.37	1,142	0.34
			2-series				
Compatible Cross	VI	1939	2-5*	53.5	20.4	146	7.7
			2-14	55.5	17.2	125	8.6
	VII	1940	2-3	77.4	66.0	446	34.3
			2-13*	85.5	78.8	325	32.3
	Av. and total			68.0	45.6	1,042	12.8
Incompatible Cross	VIII	1939	2-4	63.9	1.84	250	0.64
			2-13*	74.0	0.52	114	0.38
	IX	1940	2-5*	63.7	2.20	250	2.58
			2-15	61.6	4.44	383	2.33
	Av. and total			65.8	2.25	997	1.75

*These plants have been used in both compatible and incompatible crosses.

flowers per head on sister F_1 plants of the 1-series,[5] but the seed-set with the compatible crosses (cages I and II) was about 80 and 90 times, respectively, as great as with the incompatible cross (cage IV). An even greater difference was observed in 1940 between cages III and V. A similar relationship held with plants of the 2-series in both 1939 and 1940 under cages VI to IX. It should be noted that in both the 1- and 2-series some of the same plants were used in both com-

[5]Results of crossing among the 1-series in the greenhouse have already been reported (1) and those from the 2-series will be described in the near future.

TABLE 2.—*Seed-set with self-pollination under bee cages (first harvest) and under bag.*

Cage No.	Year caged	Plant No.	25 "best" heads under cage		All heads under cage		Heads bagged*	
			Flowers per head, av.	Seeds per head, av.	Total No.	Seeds per head, av.	Total No.	Seeds per head, av.
X	1939	55(4)	53.0	1.20	186	0.66	—	—
		55(x)	52.4	1.08	113	0.57	—	—
		55(5)	56.4	0.96	139	0.60	—	—
		Av. and total	53.9	1.08	438	0.62	44	6.57
XI	1939	70(3)	74.9	1.16	250	0.91	—	—
		70(x)	74.8	1.56	204	1.04	—	—
		70(4)	73.2	1.36	287	1.04	—	—
		Av. and total	74.3	1.36	741	0.99	48	1.69
XII	1939	58(1)	78.7	17.4	208	11.4	—	—
		58(x)	71.2	17.0	115	10.1	—	—
		58(2)	67.3	23.8	236	15.5	—	—
		Av. and total	72.3	19.4	559	12.8	32	49.2
XIII	1940	102(1)	68.0	2.24	243	0.91	—	—
		102(x)	67.5	1.40	239	1.02	—	—
		102(2)	75.6	1.04	185	0.77	—	—
		Av. and total	70.4	1.56	667	0.91	94	7.52
XIV	1940	198(4)	57.5	2.16	141	1.91	—	—
		198(x)	56.1	2.48	75	2.00	—	—
		198(5)	61.5	3.36	100	2.15	—	—
		Av. and total	58.4	2.66	316	2.01	66	5.00
XV	1940	454(1)	68.8	13.9	255	14.2	—	—
		454(x)	68.2	17.9	275	14.3	—	—
		454(2)	68.5	11.1	300	12.9	—	—
		Av. and total	68.5	14.3	830	13.8	98	20.5
XVI	1940	442(4)	82.0	187.5	511	116.8	—	—
		442(x)	79.1	164.4†	425	118.7†	—	—
		442(5)	85.2	169.2†	631	106.4†	—	—
		Av. and total	82.1	173.7	1,567	113.1	94	159.3

*Three manipulations.
†Calculated from weight of seeds per head in comparison with weight of those counted from plant 442(4).

patible and incompatible crosses. All plants were highly cross-compatible if mated with plants of different compatibility groups (different genotypes in regard to the S factors), but were cross-incompatible when mated with plants of the same group (same S genotype). All of these relationships under bee cages confirm those

established in the greenhouse with hand-pollination. These differences in seed-set between compatible and incompatible crosses, although somewhat less than those obtained in the greenhouse, are highly significant and would be of importance in any breeding program.

Bee pollination resulted in a larger number of seeds per head on selfing the highly self-compatible plant under cage XVI (Table 2) than when crossing any compatible plants. The other plants listed in Table 2 show varying degrees of pseudo-self-compatibility, and in every case usable quantities of seed were produced. The differences between plants in ability to set self-seed with bee pollination were comparable to the differences when measured by manipulation under bag (Table 2), and the latter have proved heritable in the first inbred generation. The variability in seed-set between heads on the same plant generally was less with bee pollination than with hand-pollination under bag.

The variances obtained in the number of flowers and seeds per head are summarized in Table 3. Significant differences between cages in seeds per head were obtained in every class of plants except that of medium self-compatibility. In this class there were only two cages,

TABLE 3.—*Analyses of variance of flowers and seeds per head from "25 best heads" under all cages.*

Type of pollination	Character		Between cages		Plants within cages		Heads within plants	
			D.F.	Variance	D.F.	Variance	D.F.	Variance
Cross-pollination	Flowers per head		8	7,694.9*	11	1,059.4*	480	111.4
	Seeds per head	Compatible (I, II, III, VI, VII)	4	20,530.9†	6	2,546.5*	264	589.2
		Incompatible (IV, V, VIII, IX)	3	103.8†	5	17.5	216	14.4
Self-pollination	Flowers per head		6	6,909.5*	14	275.7*	504	86.5
	Seeds per head	Low compatible (X, XI, XIII, XIV)	3	36.2†	8	5.1	288	4.1
		Med. comp. (XII, XV)	1	977.9	4	329.8	144	186.4
		High compatible (XVI)	—	—	2	4,287.8	72	6,601.3

*Highly significant differences (exceed odds 99:1).
†Significant differences (exceed odds 20:1).

and the plants they contained proved very similar in degree of self-compatibility. On the other hand, a significant difference between plants within cages was obtained only for the compatible cross-pollinations. This was to be expected, however, considering the nature of the classes used. The plants used in cross-pollinations differed in seed-setting ability (see below), but when used in incompatible crosses this inherent ability could not be adequately expressed since the differences were neither large enough nor consistent enough to be statistically significant. Likewise, no difference between plants in the self-pollination cages was expected since all plants within each cage were clones of a single individual. The variance obtained within plants was included in the table to give an idea of the large amount of variation that can be attributed to this source. This is often not considered when presenting seed-set data on plants of different degrees of compatibility. In most cases a relatively large number of observations need to be taken to obtain satisfactory averages for the plants.

The average seed-set from the 25 best heads of the seven plants used in compatible crosses in 1939 varied from 21.2 to 49.1 (Table 1). These values show a significant correlation with the number of ovules produced per pod (1). Since the seed-setting is determined in part by the number of ovules per pod and is apparently inherited, it might be one of the considerations in a practical breeding program.

SELF-POLLINATION IN THE FIELD

Most of the self-pollinations in the field were made under bags of fine muslin, about 3½ inches × 5½ inches when folded flat. The bags were supported by pieces of wire, 12 or 15 inches long, bent over at a little more than right angles about 3 inches from one end to keep the bag stretched out at the top while the other end of the wire was pushed into the ground. Wherever possible, two sturdy heads on which the lowermost flowers appeared ready to open within the next day were enclosed in a single bag. The bag was closed near the bottom by wrapping around it the string of a Dennison's marking tag, slipping the tag through the loop of the string, and pulling the string fairly tight.

When 190 heads on 76 plants were enclosed in bags but not artificially pollinated during the summer of 1937, the average seed-set per head was 0.5. This is about eight times that obtained by Williams (5), but is low enough to indicate that these plants of white clover were almost incapable of setting seed in the absence of pollinating agents. From 176 plants of another series where the heads were manipulated once each day for 6 days after bagging, the average seed-set per head was increased to 8.5. The manipulation consisted of gently rolling the enclosed heads between thumb and fingers without removing the bag. In 1938, about four heads on each of 615 other plants yielded an average seed-set of 5.7 per head when manipulated. Ten per cent of these plants did not produce any seeds, 73% yielded less than 10 per head, 16% yielded between 10 and 50, and 1% yielded over 50. This is considerably more seed than was obtained by Williams (5) when he

self-pollinated by hand. He reported that only about one-quarter of his plants set seeds.

A comparison was made on 28 plants during the summer of 1938 between six manipulations, three manipulations (every other day after bagging), and one manipulation (on the third day after bagging). The results were not conclusive in every case, but it appeared that six manipulations were not necessary for the best results. This experiment was repeated in 1939, using clones of the same three plants as those selfed in bee cages and using from 16 to 24 heads per treatment (Table 4). The seed-set after one manipulation was definitely inferior to three or six manipulations, but there appeared no consistent differences between the last two. For most purposes, the three manipulations seem adequate.

TABLE 4.—*Average seed-set per head early and late in flowering period when manipulated one, three, or six times.*

Plant No.	Heads per manipulation treatment	Number of manipulations on					
		June 6, 1939			July 6, 1939		
		1	3	6	1	3	6
37W16(8) (Same as Cage XI)	24	1.1	1.6	1.9	0.1	1.8	1.5
37W47(76) (Same as Cage X)	22	3.4	6.0	7.2	1.5	7.2	4.6
37W58(160) (Same as Cage XII)	16	43.6	51.8	49.6	9.1	46.7	59.4

SUMMARY

Methods are described which have been found to be the most satisfactory for growing white clover in the greenhouse to obtain an abundance of flowers for controlled pollinations.

Suction emasculation has been adapted to white clover (with certain modifications) to yield satisfactory results.

When six plants of different degrees of pseudo-self-compatibility, all with recessive solid green leaves, were crossed as females, using three methods, with a plant homozygous for a dominant leaf marking, it was found that accidental self-pollinations occurred only rarely. Emasculation is performed primarily to allow an easier and more certain application of the pollen.

The seed yields obtained on pseudo-self-compatible plants under bag in the field were more closely approximated in the greenhouse by rubbing entire heads than by the supposedly more precise pollination with a toothpick using only 10 flowers per head.

When five compatible and four incompatible crosses were made with bee pollination under cages in the field, the differences between crosses and between plants in number of seeds set were similar to those obtained by hand-pollination in the greenhouse. Similarly, the differences in seed-set between seven self-pollinations made by bees under cages were confirmed under bag in the field.

The rubbing of entire heads in the field without removing the muslin bags in which the heads are enclosed is necessary for self-pollination of most plants. With three manipulations on every other day after bagging as many seeds resulted as when the heads were manipulated every day for 6 days.

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A STUDY OF METHODS OF BREEDING ORCHARD GRASS, *DACTYLIS GLOMERATA* L.[1]

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ORCHARD grass production is most intensive in Kentucky, Tennessee, Missouri, southern Illinois, and Indiana. It is also important in Virginia, Maryland, and West Virginia and to a lesser extent southwest and north of these states. This crop has been placed fourth to fifth in importance among the cultivated perennial pasture and hay grasses in America. Small and old isolated patches of orchard grass are found in waste places and meadows in Minnesota. These are found in protected locations on the south facing hillsides, places which normally have heavy snow covers, and semi-wooded areas. If it were possible to obtain a strain of orchard grass adapted to Minnesota it would be of considerable value as a perennial hay and pasture plant.

It seemed that selection of material from these isolated stands in Minnesota promised to be an initial source of naturalized orchard grass for that state. Therefore, collections of native and introduced strains were made as a basis for a study of orchard grass improvement. The main objectives were to compare winterhardiness of naturalized and introduced strains under field conditions and in cold temperature chambers; to determine the effects of self-fertilization in relation to methods of breeding; and to investigate the extent of genotypic variability in important characters.

REVIEW OF LITERATURE

Until the last decade very little breeding work has been done in the United States on any of the grasses except timothy. The Welsh Plant Breeding Station has contributed more to the breeding of forage grasses than any other station. Stapledon (22)[3] and Jenkin (11) from that station in 1931 described methods and technics employed in breeding various grasses.

The preliminary step made by Stapledon (22) for obtaining breeding stocks was the collection of seeds and plants from native sources. All individuals obtained from these stocks were classified into not more than a dozen main growth-form types. These types were then set out in replicated space-planted nurseries and close-planted tiller beds. As a result of studies of yield, persistence, leafiness, palatability, seed setting, and chemical composition were noted, three types of

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[3]Figures in parenthesis refer to "Literature Cited", p. 557.

growth-form groups were selected, *viz.*, one considered ideal for hay, one for dual-purposes, and one for pasture.

Jenkin (11) also collected native material, but here the selected individuals were selfed by use of bags, and, inter-crossed by hand or by placing of pairs of inflorescences together under bags for mutual pollination. In the building of a strain, a single selected plant, several plants, or an entire population from a particular source was used as the basis.

Calder (2) in New Zealand collected orchard grass plants from old pastures, grew them in clonal line rows under grazing by sheep, and after three years the best types were selected for breeding. These selected plants were selfed by isolating them at 20-rod intervals in a tall oat field. Selfed seed from individual plants was sown in greenhouses and progenies transplanted into the field plots. These plots were grazed again by sheep for several years after which the parents producing the best progenies in these plots were selected for vegetative propagation and seed production.

Nilsson (18) and Stapledon (23) both reported variations from complete fertility to absolute self-sterility in orchard grass. Large differences were observed by Nilsson in height of plant of different selfed progenies. Reductions in vigor in 2- and 3-year selfed progenies of 50% or more were observed by Stapledon.

Wolfe and Kipps (24) reported the seed setting range of orchard grass when the heads were covered with paper bags to be 1 to 17%, when the entire plants were covered with cloth cages 1 to 27%, and when the plants were open-pollinated 7 to 50%.

A summary of the effects of self-fertility in many grasses was made by Beddows (1). He concluded that the perennial grasses were, as a general rule, relatively low in the amount of self-fertility as compared to the annual plant group. The self-fertility of orchard grass when expressed as a ratio of open-pollinated over self-pollinated, "Free over Enclosed", had a value of 6.16.

The most extensive cytological work on Dactylis was done by Müntzing (16, 17). The tetraploid species, *D. glomerata*, was found to be unstable cytologically with at least 10% of the individuals having aberrant chromosome numbers. He found that plants with 28 chromosomes were twice as vigorous, on the average, as those individuals with 14, and those with 21 chromosomes were intermediate. Aneuploids were greatly lacking in vigor. Pollen fertility was high in the 14- and 28-chromosome individuals, but the fertility was low or entirely lacking in the plants with intermediate chromosome numbers.

Myers and Hill (14) found in the root tip studies of 116 plants of orchard grass that 59% had 28 chromosomes, 22% 27 chromosomes, 12% 29 chromosomes, and 7% 30 chromosomes. The number of quadrivalents per microsporocyte varied from 1 to 7, the average quadrivalent frequency being 3.9 per cell. Myers (15) recently reported data on chlorophyll deficiencies in orchard grass that were explained on the basis of tetrasomic inheritance.

The genotypic response of grass species to habitats was studied by a number of investigators who showed that there are present within species definite hereditary ecotypes. With orchard grass, Kattermann (12, 13) found that the various ecotypes he collected differed in chromosome numbers as well as in many other morphological and physiological characteristics.

Rusts, caused principally by *Puccinia graminis avenae* and *P. glumarum* are two diseases of orchard grass of economic importance, the former in America and the latter in Europe (9, 10, 21). *P. coronata*, which causes crown rust on oats

and rye grasses, also attacks orchard grass (5, 20). Rathayi disease caused by *Aplanabacter rathayi* is found only on orchard grass and is especially common and important in localized areas in Europe (19). Scald on Dactylis has been reported as sometimes fairly common but usually not important (6). Blights, root rots, and leaf spots caused usually by species of Fusarium and Helminthosporium are common and important diseases of numerous grasses (3, 4, 7, 8).

MATERIALS AND METHODS

The materials included strains from five Minnesota habitats; one commercial seed lot; five numbered forage crop strains from the U. S. Dept. of Agriculture; two lots of seed, including the Avon variety, from Canada; and two strains each from Aberystwyth and Germany and one from New Zealand. A naturalized orchard grass stand growing locally near St. Paul, Minn., was used as the chief source of breeding material. This strain has grown wild in this somewhat protected place for 30 to 50 years. Head selections were made from this habitat. Subsequent 1-, 2-, and 3-year selfed progenies from this original source were the basis for the more intensive studies.

Observations on winterhardiness were made on all strains grown. Intensive studies were made on several of these strains and their clonal and selfed progenies. This character was studied under field conditions where the plants were space-planted 2 by 3 and 3 by 3 feet and in replicated clonal lines. These clonal line plantings were rows 6 feet long and 3 feet apart, with the vegetatively propagated pieces 6 or 9 inches apart within the row. Field hardiness was recorded in percentage values based on the amount of permanent injury after allowing time for recovery and growth.

Cold resistance of clonal lines was studied from material grown in pots in a greenhouse. They were subjected to a 12-day hardening-off period at 2° C before freezing at −10° C for 24 hours. After freezing, the plants were thawed out at 2° C for 40 hours and given increased temperatures later for recovery and growth. Cold resistance was recorded in six classes based on the relative amount of survival after a 2-week recovery period.

Self-fertility studies were made primarily on a local naturalized strain referred to before and its 1- and 2-year selfed plant generations. Selfing studies were made also on eight other strains of orchard grass from different sources. Self-pollination was affected by placing a 4 by 10 or 4 by 18 inch parchment bag over five panicles per plant. At maturity five open-pollinated heads and those under the bag were harvested, threshed separately, and a portion of each seed lot germinated in a large glassed-in germinator for the self-fertility evaluation. It was difficult to count accurately the number of fertile seeds in orchard grass; therefore counts of seedlings instead of seeds were made and self-fertility expressed in a ratio of the number of open-pollinated seeds to self-pollinated. The seedlings desired for progenies of each lot were picked from the germinator blotter and transplanted into greenhouse flats for growing. Remnant seed was used for greenhouse and field plantings after the self-fertility value of each seed lot had been determined.

In germinating many lots of selfed orchard grass seeds, albino and chlorina type plants appeared. A record was made of the number of albinos. All seedlings from selfed seed lots were classified into five classes for seedling vigor as expressed when grown in a day-light seed germinator.

Rust and leaf spots were diseases of major importance and were studied under field conditions. The rust was identified by Dr. M. N. Levine as caused by *Puc-*

cinia graminis avenae. This disease was in epidemic proportions in 1938 and 1939 in all of the orchard grass nurseries. Notes on rust reaction were obtained on eight strains and their clonal and selfed progenies. The data were taken in five classes, namely, 1, no rust; 2, trace infection; 3, light infection; 4, moderate infection; and 5, heavily rusted.

Leaf spots were particularly prevalent and injurious in 1939. Several types of leaf spot diseases were observed, but the important one produced rectangular shaped spots more than 5 mm in width and very dull black in color. On some plants the spots were few and scattered and on others they were so extremely numerous that they coalesced, producing large solid areas taking in the complete width of the leaf. The casual organism was identified by Dr. J. J. Christensen as *Scolecotrichum graminis* Fckl., but *Helminthosporium* Spp. were found associated with this disease. The first generation selfed plants from eight orchard grass strains grown in 1939 were classified in five broad classes for leaf spot resistance.

Other characters studied in the field besides winterhardiness, self-fertility, and disease reaction were yield, plant type, plant height, and number of panicles. These characters were noted for the individual spaced plants in the various nurseries as well as for the plants in replicated clonal lines. Yields were taken on a basis of grams of hay per plot with cuttings always made at the full bloom stage. Plant type was classified under three classes, namely, tussock, intermediate, or erect; the tussock type of plant, strictly a basal-leaf bunch growth; the erect type, a strongly stemmy and few-leafed growth type; the intermediate type, a growth form between the other two classes. Plant height was measured in inches from the ground to the average height level of the panicles. Individuals that did not produce panicles were omitted entirely from height measurements. The number of panicles per plant was an actual count when the numbers were small and a careful approximation when the numbers were large.

Characters of individual nursery plants were correlated with the characters of replicated clonal lines from these same plants.

EXPERIMENTAL RESULTS

WINTERHARDINESS

The most intensive studies were carried out with a naturalized source that had grown wild for many years in a local habitat. Forty-five head selections from as many different plants were made from this habitat and 10-plant progenies from each were grown in an unprotected grass nursery. Only 38 plants, or 9%, of these individuals survived the first winter following planting.

Thirty-three of the 38 survivors when bagged produced selfed seed and subsequently first generation selfed progenies. All 1-year selfed progenies were at least 80% winterhardy. This high survival was due to an unusually mild winter.

Selection was made of 101 vigorous and otherwise superior appearing 1-year selfed individuals, and these and their corresponding parents were grown in clonal lines in duplicate at University Farm and Waseca for a comparative test. The average hardiness of the parents was 10% and that of the progenies of the selected 1-year selfed plants only 13%. A test of association between the parents and their progenies was made. A significant correlation coefficient of

$r = .45$ was obtained which showed a tendency for winterhardy parents to produce winterhardy selfed plants.

Selfed seed was obtained from 62 of the 1-year selfed plants. Two-year selfed progenies, with an average of 16 plants each, were set out in the field nursery. The winterhardiness range on a progeny basis was from complete winterkilling to moderate hardiness with some outstanding progenies appearing. The distribution of the 62 2-year selfed progenies in five 20% hardiness classes is given in Table 1.

TABLE 1.—*Average winter survival of 62 2-year selfed progenies of orchard grass grouped into five classes based on percentage of hardiness.*

Number of progenies per winterhardy percentage class of				
0–20%	21–40%	41–60%	61–80%	81–100%
12	21	18	9	2

The average hardiness of all the 2-year selfed plants was 40% and of all the commercial check plants 59%. One-fourth of the selfed progenies were equal or superior to the commercial checks in winterhardiness.

A selected group of 66 winterhardy plants from this 2-year selfed population and a group of 15 hardy commercial plants were grown in a triplicated clonal line field test. Winterhardiness, based on degree of injury and spring recovery, was noted for these two groups of clones. Highly significant F values were obtained for field hardiness differences within the selfed group and within the commercial check group of clones, but no difference was found between the two groups (Table 2).

TABLE 2.—*F values obtained for field winterhardiness and laboratory cold resistance of 66 2-year selfed and 15 commercial check plants of orchard grass grown in replicated clonal lines.*

Clonal lines	F values for	
	Field winterhardiness tests	Laboratory cold resistance tests
2-year selfed lines	4.08*	12.00*
Commercial checks	3.17*	1.64
2-year selfed lines vs. commercial checks	0.10	112.05*

*Exceeds 1% level of significance.

Plant material of these same 66 2-year selfed plants was tested for cold resistance in a freezing chamber. Clonal progenies of 15 commercial plants unselected for winterhardiness were grown, the checks in the laboratory freezing studies being entirely different than in the field trials. Four clonal pieces of each plant were grown in pots in the greenhouse before subjection to the cold test. The analysis of the results gave a highly significant F value for variation due to 2-year selfed clones as shown in the right hand column of Table 2. The com-

mercial clones did not differ among themselves, but as a group they differed significantly from the 2-year selfed clones as shown by the F values in Table 2. Not a single one of the 15 commercial checks was above the general mean of all clones, showing definitely a lack of resistance to freezing injury when compared with the group of selfed plants.

In order to test the relationship between the winterhardiness values obtained in the field and the cold resistance values obtained in the freezing chamber where highly significant F values were obtained for clones in each case, the two series of values for the 2-year selfed clonal lines only were correlated. The correlation coefficient obtained was $r = .05$ which was not significantly different from 0, hence it was concluded that the winter hardiness field test and the laboratory freezing test were not tests of the same physiological character.

Eighteen other strains from different sources and collections were grown in the space-planted and accession forage nurseries and their relative winter survival noted. The German strains were extremely low in winterhardiness and the Welsh and New Zealand strains only slightly more hardy. The strains from these three sources, however, produced excellent appearing plants, but they lacked the necessary hardiness for winter survival. The orchard grass strains from the Canadian source were superior, and, several strains from the U. S. Dept. of Agriculture and several local collections also ranked high in winterhardiness. These trials were not made in sufficient detail definitely to rank the various strains in order of winterhardiness.

SELF-FERTILITY

In general, there was sufficient self-fertility present in this orchard grass material for the production of selfed progeny lines. Self-fertility, given as a ratio of F/I, where F/I refers to free over isolated of the 38 parental plants when bagged in three different years, is given in Table 3.

The seed setting under selfing from one year to the next varied greatly. These plants gave individual self-fertility values of 1, 2, etc., up to no seed set, with average values for the entire 38-plant group for the three years of 8, 4, and 49, respectively. The results from the best two years, 1935 and 1937, when correlated gave an $r = .30$ which value only approaches the 5% point level of significance. There were a considerable number of plants that set seed freely when selfed in both 1935 and 1937.

One- and 2-year selfed plants when bagged for selfing gave fertility values also ranging from apparently complete self-fertility to high self-sterility. A nearly significant correlation coefficient of $r = .32$ was obtained when correlating the self-fertility values of the parental plants and their 1-year selfed progenies.

Self-fertilization studies were made on eight other collections and strains of orchard grass. When selfing about 25 plants per strain the most fertile strain gave an average self-fertility ratio value of 14, the second 37, etc., and the one most self-sterile, 272. Only one strain had several plants which were considered highly self-fertile.

These results were obtained in 1938, the year in which low selfed seed setting was obtained from the 38 parental plants referred to in Table 3.

TABLE 3.—*Self-fertility of the 38 parent orchard grass plants for 3 years with seed setting given in ratios of F/I, free over isolated.*

Parent plant No.	F/I 1935	F/I 1937	F/I 1938	Parent plant No.	F/I 1935	F/I 1937	F/I 1938
0-1-M	1	11	Inf*	0-20-M	3	3	X
0-2-M	3	7	Inf	0-21-M	23	11	500
0-3-M	9	25	420	0-22-M	50	9	X
0-4-M	17	2	150	0-23-M	2	4	4
0-5-M	100	5	11	0-24-M	300	100	104
0-6-M	3	1	21	0-25-M	150	4	35
0-7-M	160	33	X†	0-26-M	10	33	635
0-8-M	10	2	X	0-27-M	100	—	—
0-9-M	43	19	X	0-28-M	20	2	23
0-10-M	21	60	X	0-29-M	75	—	35
0-11-M	10	4	X	0-30-M	300	6	175
0-12-M	Inf	—	—	0-31-M	—	2	—
0-13-M	Inf	Inf	Inf	0-32-M	17	3	Inf
0-14-M	150	50	Inf	0-33-M	1	2	X
0-15-M	Inf	8	X	0-34-M	24	8	—
0-16-M	Inf	2	Inf	0-35-M	50	1	23
0-17-M	5	3	Inf	0-36-M	37	3	70
0-18-M	6	2	Inf	0-37-M	37	2	Inf
0-19-M	5	2	Inf	0-38-M	75	—	X

*No selfed seed set.
†No panicles produced by the plant.

No cytological examination was made of this material. It seems reasonable to assume, however, that variations between individual plants in self-fertility may have been due, at least in part, to aneuploidy. Previous reports of cytological investigations on orchard grass have shown that pollen fertility was very low or entirely lacking in individuals with chromosome numbers other than the euploid number.

During the course of study of self-fertility in orchard grass, many albino and virescent seedlings appeared. Albino seedlings from parental, 1-year selfed and 2-year selfed plants ranged from none to 20% with a few yielding higher percentages, but these were based on small seed lots. This range was obtained also for the 38 parent plants selfed three different years. An $r = .31$ was obtained when correlating the albino percentages from the two best seed years. This coefficient, however, did not reach the 5% level of significance. No genetic analysis of the albino frequencies was attempted as the number of plants per progeny from the parental plants and later selfed generations were considered insufficient.

DISEASE STUDIES

A heavy epidemic of rust appeared during 1938, the year the extensive 2-year selfed progenies were grown. Another epidemic came

the following year, but there was practically no rust in the several previous years. Rust readings made in five broad classes on the 2-year selfed plants showed some progenies were uniformly resistant and others uniformly susceptible to rust. Also, the plants in many of these selfed progenies were usually distributed in two and sometimes in three adjacent rust classes.

The rust reaction of orchard grass plants from eight collections and introductions showed that each of these strains had plants classified in all five rust classes. Some of the strains were attacked much less than others. Forty-three 1-year selfed progenies obtained from these eight strains were distributed chiefly in three adjacent rust classes. A few progenies were uniform for resistance, while others were completely susceptible. When correlating the rust class value of parent plants and the average value of their selfed progeny, a significant $r = .72$ was obtained.

An epidemic of leaf spot occurred during the second rust year and data in five classes, based on relative amounts of infection, were taken on the 1-year selfed progenies from the eight orchard grass strains just considered. This disease caused large and dull black spots on the leaves and considerable damage to the forage and threatened the life of the plant. One-third of the progenies, well distributed among the eight strains, were free of leaf spot and the others had varying amounts of resistance. The individuals of many progenies fell mainly into one or two adjacent leaf spot classes, although a few progenies had plants in all five classes.

There was a striking negative relationship between leaf spot and rust. Where the plants were severely injured by the rust, which always came early, there was little opportunity for them to be infected with leaf spot as a large part of the leaf area was covered with rust pustules. Both diseases were uniformly distributed and in epidemic proportions throughout the orchard grass nursery. There were some entire progenies and some plants in other progenies, however, that were essentially rust and leaf spot free.

Diseases of secondary importance observed on orchard grass plants were noted. Ergot was found on numerous plants but was of no particular importance. Careful examination revealed the presence of root rots on seedlings and on older plants, usually those which had suffered severe winter injury. Powdery mildew, caused by *Erysiphe graminis*, a disease organism very specific as to host, was found on only a few plants in several selfed progenies.

PLANT CHARACTERS

Yield, plant type, plant height, and number of culms were studied on the first and second selfed generation and in the parent plants of orchard grass when grown in a space-planted nursery. Each parent was compared with superior individuals selected from its 1-year and 2-year selfed progenies. The average character values for the three plant generations are given in Table 4.

On the average, the 1- and 2-year selfed plants yielded only 60% and 43%, respectively, as much as the parents. There was little effect of inbreeding on the plant type. The average plant heights

for the parents and the 1-year and 2-year selfed plants were 31.7, 28.3, and 25.3 inches, respectively. There was also a rather uniform reduction in number of culms per plant, the parents averaging 80.2 culms, the 1-year selfed plants 50.4, and the 2-year selfed plants 32.4. However, a number of families had plants in both the first and second selfed generations that were equal in yield, plant height, and number of culms to their corresponding parents.

TABLE 4.—*Average character values of the parental and selected 1- and 2-year selfed plants grown for comparison.*

Character	Generation		
	Average of parents	Average of 1-year selfed	Average of 2-year selfed
Yield, grams	940	560	403
Plant type, class 1 to 3*	1.70	1.82	1.87
Plant height, in.	31.7	28.3	25.3
Number of culms	80.2	50.4	32.4

*Plant type was taken in three classes: 1, tussock; 2, intermediate; 3, erect.

A group of 66 2-year selfed and 15 commercial check plants of orchard grass grown in triplicated clonal lines were studied for plant characters, yield, plant type, height, number of culms, and percentage protein. Data were taken on each of the three hay crops produced. The results are given in Table 5 for each hay crop separately on the clonal line group basis, i.e., 2-year selfed lines and commercial check lines.

TABLE 5.—*Summary of character values obtained on the first, second, and third hay crops of a selected group of 66 2-year selfed and 15 commercial check plants of orchard grass grown in triplicated clonal lines.*

Character	Crop	Group of clones		
		Commercial	2-year selfed	Significance of difference, commercial clones vs. 2-year selfed clones
Hay yield, grams	1st	634.1	430.9	Highly significant
	2nd	1,158.9	725.1	Highly significant
	3rd	1,407.7	866.6	Highly significant
Plant height, in.	1st	31.7	26.5	Highly significant
	2nd	34.6	28.2	Highly significant
Plant type, class*	1st	1.84	1.95	Non-significant
	2nd	1.91	1.89	Non-significant
	3rd	1.44	1.72	Highly significant
Number of culms	1st	73.7	64.9	Highly significant
	2nd	63.0	45.7	Highly significant
	3rd	23.7	13.6	Highly significant
Protein, %	1st	16.3	16.5	Non-significant

*Plant type was taken in three classes: 1, tussock; 2, intermediate; 3, erect.

For each of the four characters studied, hay yield, plant height, plant type, and number of culms per plant, there was a significant difference between the commercial clones and the inbred lines except for plant type for the first two hay crops. High F values were obtained indicating the significant differences among the plant clones within the 2-year selfed group and among those within the commercial check group for all five characters given in Table 5.

The commercial group of clones averaged significantly higher in yield, grew taller, and produced a greater number of culms than the 2-year selfed lines. Nevertheless, it was notable that a number of the superior individuals of the selfed group were for every character studied fully equal to the better ones of the commercial check group. These superior 2-year selfed clones gave consistent results in all three hay harvests.

CORRELATION STUDIES

By means of simple correlations, tests of association of characters of plants grown in the nursery in one year and in triplicated clonal lines the following season were made for plant type, height, number of culms, and rust reaction. The nursery plant character readings were taken on the one and only crop growth, whereas the readings of the clones were made on each of the three hay crops and these correlated separately with the nursery plant readings. Coefficients of correlation are given in Table 6.

TABLE 6.—*Correlation of plant type, plant height, number of culms, and rust reaction of orchard grass plants grown in the plant nursery in one year and in triplicated clonal lines the following year; the nursery plant correlated separately with each clonal hay crop.*

Clonal line crop	Plant type	Plant height	No. of culms	Rust reaction
First	0.638*	0.564*	0.049	——
Second	0.690*	0.760*	0.585*	0.540*
Third	0.454*	——	0.057	0.652*

*Exceeds 1% level of significance.

All correlations were highly significant except those for the first and third crops for number of culms. The coefficients of correlation in Table 6 show the extent to which a study of the individual nursery plant may be an index of its performance in clonal lines.

Studies of interrelationships of a number of characters were made on the triplicated clonal lines of the 66 selected 2-year selfed plants. These character interrelationships were studied by means of simple correlation coefficients. All correlations were made within crops, i.e., yield of the first crop was correlated with plant type of the first crop, yield of the second crop was correlated with plant type of the second crop, etc. The results obtained for these correlated character studies are given in Table 7.

Yield was highly correlated with winterhardiness for each of the three crops of hay. Yield was also positively correlated with plant height and number of culms for the first crop, but was negatively correlated with erect plant type, percentage rust infection, and num-

ber of culms for the second crop. Plant height was correlated positively with number of culms and negatively with percentage protein. Percentage protein and erect plant type and percentage protein and number of culms were also negatively correlated. No important relationships were found between the other combinations of characters.

TABLE 7.—*Interrelationships of yield, plant type, plant height, number of culms, per cent rust, percentage protein, and winterhardiness of orchard grass as shown by simple correlation coefficients.*

Characters	Crops	Percentage rust	No. of culms	Plant height	Plant type	Yield	Winterhardiness
Percentage protein	2nd	−0.07	−0.56*	−0.37*	−0.48*	0.17	—
Percentage rust	2nd	—	0.35*	0.01	0.32*	−0.01	—
	3rd	—	—	—	0.25†	−0.42*	—
No. of culms	1st	—	—	0.58*	0.04	0.70*	—
	2nd	—	—	0.02	0.82*	−0.26†	—
Plant height	1st	—	—	—	−0.13	0.77*	—
	2nd	—	—	—	−0.10	0.49*	—
Plant type	1st	—	—	—	—	−0.49*	—
	2nd	—	—	—	—	−0.51*	—
	3rd	—	—	—	—	−0.39*	—
Yield	1st	—	—	—	—	—	0.94*
	2nd	—	—	—	—	—	0.62*
	3rd	—	—	—	—	—	0.75*

*Exceeds 1% level of significance.
†Exceeds 5% level of significance.

NEW POTENTIAL STRAINS

Recombination by mass pollination was made of selected orchard grass material for the production of two new strains. One came from the interpollination of a group of 12 superior 2-year selfed plants whose original source was a local habitat and 4 superior commercial check plants all of which had been tested in replicated clonal lines. The other strain resulted from the interpollination of 72 of the most superior first generation selfed plants from eight different collections of orchard grass from northern sources. Extensive tests of these two strains will be made in Minnesota beginning in 1941.

SUMMARY OF RESULTS

A study was made of the winterhardiness of naturalized and introduced strains of orchard grass, the effects of self-fertilization, and genotypic variability of certain important plant characters.

Eighteen selected strains and many selfed lines from a single collection varied widely in winter survival. Winterhardy plants tended to produce winterhardy selfed progenies. No correlation was found be-

tween winterhardiness in the field and cold resistance in the freezing chamber.

A wide range of self-fertility was found between and within selfed progenies and between open-pollinated plants from eight collections or strains. The amount of selfed seed produced varied greatly from year to year.

Reaction to stem rust, *Puccinia graminis avenae*, varied from complete resistance to extreme susceptibility in all open-pollinated strains studied. Uniformly resistant 2-year selfed lines were obtained. Similarly, under a leaf spot disease epidemic, selfed progenies were found which were uniformly leaf spot resistant.

The means for yield, plant height, and number of culms of 1- and 2-year selfed progenies were progressively lower than the means for the same characters of the parents.

A study of a number of agronomic characters was made on a group of selected 2-year selfed plants and a group of open-pollinated plants all grown in a clonal line test. Significant differences were found within the 2-year selfed group, within the open-pollinated group, and between the two groups for every character studied. A number of vigorous clones were found in the 2-year selfed group which were fully equal to the superior individuals in the open-pollinated group.

It was shown that plant type, plant height, and number of culms of the parent plants were positively and significantly correlated with the means for the same characters of their clonal progenies when grown in the following year.

Under Minnesota conditions yield was positively and significantly correlated with winterhardiness, plant height, and number of culms in the first crop, and, negatively and significantly correlated with erect plant type, percentage rust infection, and number of culms in the second crop.

Two new potentially promising strains were made by means of mass pollination of superior individuals selected from 1- and 2-year selfed and open-pollinated plants from northern sources. Extensive tests of these strains will be made in Minnesota beginning in 1941.

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A NEW FACTOR FOR RESISTANCE TO BUNT, *TILLETIA TRITICI*, LINKED WITH THE MARTIN AND TURKEY FACTORS[1]

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THE development of the backcross method of plant breeding has provided the plant breeder with a precise method of incorporating disease resistance into commercial varieties of grain. The requirements for this method are, first, an acceptable commercial variety, and second, a known genetic factor for resistance to the race or races of the disease in question. Therefore, a study and cataloging of the various factors for disease resistance with regard to the nature of their inheritance and with respect to the various races of the disease being studied provides valuable information for the plant breeder. Some of this information is available, but many more investigations must be made before the accumulated information approaches completeness.

The present investigation deals with the inheritance of resistance of a single wheat variety, Rio, with respect to a single physiologic race of bunt, *Tilletia tritici*. The race of bunt used was the same as that employed by Briggs in investigations of bunt resistance and has been designated as race III by Reed (14)[3] and as T-1 by Rodenhiser and Holton (15). Using this race, Briggs (3, 6, 7, 8, 9, 10, 11) has isolated three factors for bunt resistance and designated them as the Martin (MM), the Hussar (HH), and the Turkey (TT) factors. He found the Martin factor to be linked with the Turkey factor with a cross-over value of 34.22%.

El Khishen (unpublished), using the same race of bunt, has discovered an additional factor in Turkey 10016 to which he assigned the symbol XX. In Turkey 10015, in addition to the XX factor, he found a weak factor, YY.

The wheat variety, Rio, C.I. 10061,[4] has consistently shown resistance to bunt at Davis since it was first placed in the nursery in 1934. The maximum infection was 5.8% in 1937 and the average for the 7-year period is 1.2%. Sutherland and Jodon (16) report trials at Moccasin, Mont., covering 4 years in which the average infection of Rio was 4%. In 21 experiments conducted at nine different stations over the period 1932–34, Clark (12) reports an average infection of 5.8% for Rio, where Ridit showed 7.8%, Albit 22.8%, and Hybrid 128, 78.8% infection.

Since Rio is a wheat of the Turkey type we might expect its resistance to be similar to that of some of the other Turkey wheats. In the varietal trials conducted at Moccasin, Mont., by Sutherland and

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[3]Figures in parenthesis refer to "Literature Cited", p. 568.

[4]Cereal Investigation number of the U. S. Dept. of Agriculture.

Jodon, some interesting results were obtained. In trials covering the years 1930–32, Rio showed an average infection of 4%. In these same years, Turkey 1558, shown by Briggs (7) to have the Turkey factor for resistance, showed an average of 60% infection. These plants were inoculated with bunt collected locally on which the race had not been identified. It may have been a mixture of races. The observed differences between the reaction of Rio and Turkey 1558 might have been due to the fact that the resistance of Rio is due to some other factor than the Turkey factor, or the fact that Rio possesses another factor in addition to the Turkey factor, which is not found in Turkey 1558. The present investigations indicate that the factors for resistance in the two varieties are different, which would account for the differential reaction.

MATERIALS AND METHODS

The variety Rio, C.I. 10061, is a hard red winter wheat of the Turkey type. It is the result of a selection from Argentine, C.I. 1569, made at Moro, Ore., in 1920. It was distributed for commercial production by the Oregon Experiment Station in 1930 (12). Baart is a white wheat which is highly susceptible to bunt. Under favorable conditions for bunt, 80% to 100% of the plants become infected. Turkey 3055 has been demonstrated to have a single factor for bunt resistance designated as the Turkey factor (TT). Selection 1403 and Martin have the Hussar (HH) and Martin (MM) factors, respectively, and have been used as testers for these factors.

Rio was crossed with each of the other four varieties named. The cross with Baart was for the purpose of determining the number of factors present in Rio and the effect of such factors. The other crosses were to determine if any of the factors present were identical with those previously identified by Briggs.

The seed to produce the F_1 and F_2 generations was treated with copper carbonate to prevent bunt infection which would lead to differential elimination of susceptible lines. Since some genetically susceptible plants escape infection and some resistant plants become infected, the F_2 provides inadequate information, therefore the F_3 populations were used for the analysis. The use of F_3 rows for analysis removes this difficulty, since the whole row will not escape infection if susceptible, nor will the resistant rows show any great number of infected plants. Some F_2 rows were grown with the F_3 to give an indication of the behavior of the heterozygous plants.

This seed, together with all of the F_3 seed, was innoculated with smut spores by shaking in a glass container until the seeds were well blackened with spores. The spores had been collected from White Federation grown for the purpose. This collection of bunt has been propagated on White Federation since 1919 by Briggs and is the same as used by him in previous work. It has been designated as physiologic race III by Reed (14) and T-1 by Rodenhiser and Holton (15). Bressman (1) believed it to be the same as his form VIII, but Rodenhiser and Holton, using different differentials, distinguished between the two forms and designated Bressman's form VIII as T-9.

The seed was sown in the field Nov. 28–30, 1938, and Dec. 10–12, 1939. In 1938, the seed from 254 F_2 plants of the cross Rio × Baart was sown in duplicate rows with three replications in all cases where there was sufficient seed. In the cases where there was too little seed, it was sown in one or two replications. None

of the lines were eliminated due to lack of seed, and in most cases there were six rows of each progeny. Eighty seeds were planted in each row, and these produced an average of 57 plants per row. Therefore, the classification of the F_3 progenies in most cases is based on a population averaging 342 plants. The large number of rows was planted because an earlier test of this cross based on a single replication failed to show definite groups in the distribution curve and consequently genetical analysis was impossible.

In the case of the crosses with Martin, Turkey 3055, and Selection 1403, single rows from an average of 250 plants of each cross were grown. This was considered sufficient to determine whether there was segregation for susceptibility in the cross.

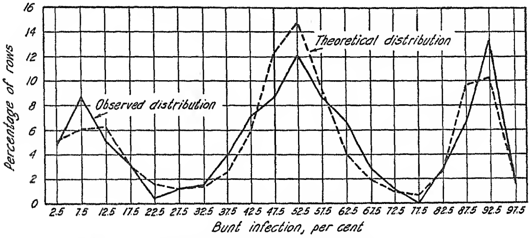

FIG. 1.—Observed distribution of F_3 rows of Rio × Baart for bunt infection compared with theoretical distribution.

About 140 additional rows each of the last three-named crosses were grown in the season 1939–40. The infection in 1940 was 80.3% for the Baart check rows as compared with 87.6% in 1939. Since the lower rate of infection in 1940 would change the limits of the classes for susceptible, heterozygous, and resistant progeny and since no Rio × Baart progenies were grown in this year, it was considered best not to include the 1940 data in this analysis. However, these data do not disagree with any of the conclusions drawn from the 1939 data.

At harvest time, the plants of each row were pulled and classified as smutted or non-smutted and the numbers recorded. Plants which showed any smutted heads were placed in the smutted class.

EXPERIMENTAL RESULTS

RIO × BAART

The F_2 population of the cross rio × Baart showed 45.6% infected plants in 1939. The Baart check rows showed 87.6% infection and the Rio checks 0.5% infection.

The distribution of the parental and F_3 progenies for smut by 5% classes is shown in Table 1 and graphically by the solid line in Fig. 1. In the distribution curve are three very pronounced modes which are separated by definite minima. Between 0% and the first minimum at 22.5% are 56 progenies. Between this point and the second at 72.5% are 127 progenies. The remaining 61 progenies fall above

TABLE 1.—*Distribution of parent rows and F_3 progenies for bunt infection by percentage classes for crosses indicated.*

Parent or cross	Percentage classes																					Total number of rows
	0–5		5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–75	75–80	80–85	85–90	90–95	95–100	
	0	0.1–5																				
Rio	6	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12
Turkey	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5
Sel. 1403	5	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
Martin	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
Baart	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	7	9	10	1	28
Rio × Baart	0	12	22	13	8	1	3	4	10	18	22	31	22	17	7	3	0	6	17	34	4	254
Rio × Sel. 1403	73	37	17	25	15	15	10	5	12	9	3	3	3	2	2	5	2	1	5	4	2	250
Rio × Turkey	113	88	23	14	3	1	1	2	1	2	—	—	—	—	—	—	—	—	—	—	—	248
Rio × Martin	98	36	34	23	16	7	8	6	6	3	5	1	2	2	0	2	1	0	1	2	1	254

72.5%. This suggests a 1–2–1 ratio of resistant, heterozygous, and susceptible progenies, which would be obtained if a single major factor for resistance were acting. The X^2 test gives a probability of .3 to .5 for this ratio, therefore, the resistance of Rio to this race of bunt is due to a single factor.

The F_2 showed an infection of 45.6% indicating that the factor must allow about one-half of the heterozygous plants to become infected. This is confirmed by the heterozygous group of the F_3 which averaged 51.4% infected plants.

In the group falling between 0% infection and 25% infection, the average infection was 9.3%. However, Rio, the resistant parent, showed only 0.5% infection. While this group is homozygous for the main factor for resistance, it appears that one or more modifiers enter from the Baart parent, whose presence allows a small percentage of plants to become infected. Briggs (3) has shown that in the cross Hard Federation × Hussar there are modifiers present which allow a small proportion of the plants to become infected, and that lines can be segregated which breed true for low percentages of bunt.

According to the formula $s = \sqrt{\frac{pq}{n}}$, the standard deviation of the heterozygous class should be 4.27%. The observed deviation was 9.62%. This difference is highly significant, therefore, there must be some factor other than random sampling affecting the dispersion of the heterozygous group. The action of modifiers will explain in part this greater dispersion of the heterozygous class.

Since the individuals falling in the susceptible group are all completely susceptible genetically, the presence of the modifiers will not affect this group. In determining the limits of susceptibility, it should be noted that the infection range of the susceptible Baart parent, as well as the location of the upper minimum of the Rio × Baart distribution curve, indicates that this limit should be at the 75% level of infection.

Insufficient data are at hand to analyze accurately the action of modifiers which must be present. However, a hypothesis giving a possible explanation may be set up. If there are two factors present in Baart which modify the Rio gene, one dominant and the other recessive in effect and of equal magnitude, then a 3–10–3 ratio will result. If each factor allows 9.0% of the resistant plants to become infected, then the group should be made up of classes with means at 0.5%, 9.5%, and 18.5%, since the resistant parent, Rio, allows 0.5% infection. This distribution would give the group a mean of 9.5% as compared with the actual mean of 9.3%. Based on these assumptions, a theoretical distribution curve for the F_3 population can be computed. Since p and q are approximately equal and N is fairly large for the heterozygous class, a normal frequency distribution can be used on this group. In the resistant and susceptible groups, since p and q are unequal, the binomial expansion will give a better estimate of these distributions.

The theoretical distribution is given in Table 2 and is shown

graphically in Fig. 1. The X^2 test gives a probability of .3 to .5 for the portion of the curve represented by the resistant group, a probability of .1 to .2 for the heterozygous group, and a probability of .1 to .2 for the susceptible group. When the entire population is considered, the probability is .1 to .2. Since each of the three portions of the curve and the entire curve as a whole fall within the limits of the 5% point of probability, the presence of modifiers explains satisfactorily the occurrence of 9.3% of smut in the resistant class and also some of the dispersion of the heterozygous class.

TABLE 2.—*Comparison of theoretical distribution of F_3 of Baart × Rio with observed distribution by percentage classes.*

Class range in %	Observed numbers		Calculated numbers		
0–5	12.0		12.8		
5–10	22.0		15.3		
10–15	13.0		15.7		
15–20	8.0	9.0	7.4	11.5	$x^2 = 3.1755$
20–25	1.0		4.1		P = 0.3—0.5
25–30	3.0	17.0	3.0	13.0	
30–35	4.0		3.5		
35–40	10.0		6.5		
40–45	18.0		14.9		
45–40	22.0		30.7		
50–55	31.0		36.9		
55–60	22.0		23.4		
60–65	17.0		10.1		
65–70	7.0	10.0	4.7	7.1	$x^2 = 9.1146$
70–75	3.0		2.4		P = 0.1—0.2
75–80	0.0	6.0	1.7	8.5	
80–85	6.0		6.8		
85–90	17.0		24.3		
90–95	34.0	38.0	25.7	29.8	$x^2 = 4.3627$
95–100	4.0		4.1		P = 0.1—0.2
Total...............					$x^2 = 16.6528$ P = 0.1—0.2

RIO × SELECTION 1403

The distribution of the F_3 lines of this cross is shown in Table 1. Fourteen lines fall above the 75% level of infection and must, therefore, be considered as completely susceptible. Since segregation does occur, the factor for resistance in Rio is not the Hussar factor found in Selection 1403.

With two factors present, one entering the cross from each parent, a ratio of 15 resistant and heterozygous lines to 1 susceptible line would be expected. In this population of 250, we would expect 15.6 susceptible lines where 14 were actually observed. The X^2 test gives a probability of .5 to .7 for a 15:1 ratio, which is a satisfactory fit. This gives further proof that the resistance of Rio is due to a single factor.

RIO × TURKEY 3055

From Table 1 it will be seen that there are no susceptible progenies in this cross, which would at first seem to indicate that the factor for bunt resistance in Rio is identical with the Turkey factor. However, Briggs (7, 9, 10) has studied crosses between Turkey 3055 and the following varieties which also contain the Turkey factor: Turkey 1558, Turkey 1558B, Turkey 2578, and Oro. In none of these crosses have the progenies produced rows with more than 25% infected plants. This is also the upper limit of the resistant class established by the Rio × Baart F_3. In the cross Rio × Turkey, however, there are 6 progenies above the 25% level of infection and these range up to 45%.

A typical curve of a cross involving the Turkey factor with susceptible Baart is shown in Fig. 2. This curve is taken from data by

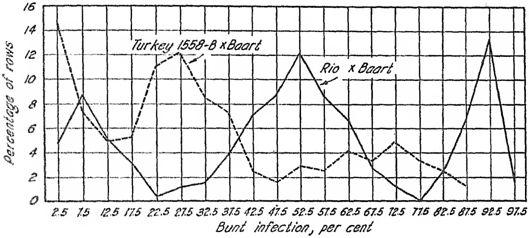

FIG. 2.—Distribution of F_3 rows of Rio × Baart and Turkey 1558B × Baart according to bunt infection.

Briggs (10) gathered in 1934. It is based on 245 rows of F_3 progeny of the cross Turkey 1558B × Baart in which the Baart check rows showed an average infection of 84.6%. This makes it comparable with the Rio × Baart data which are based on 250 progenies with Baart check rows showing 87.6% infection. A comparison of the two curves discloses noticeable differences in the distributions. There is a considerably greater concentration of rows falling in the 0 to 5% class in the cross with Turkey 1558B. In addition, the first minimum falls at 12.5% with Turkey 1558B and at 22.5% with Rio. In all other crosses involving the Turkey factor, the 0 to 5% class has been the largest class. In all except one, the first minimum has been at 12.5% infection, the exception being the cross Baart × Turkey 2578 in which case it came at the 17.5% point. Thus it is demonstrated that Rio crossed with a susceptible variety gives a distribution of the F_3 progenies which is distinctly different from that obtained when the Turkey factor is involved.

Since the factor in Rio is different from the Turkey factor, the absence of susceptible progenies in this cross must be due to close linkage between the two factors. Briggs (11) has reported a case of

linkage between factors for bunt resistance in the case of the Martin and Turkey factors. A rough estimate of linkage may be obtained from the number of progenies falling in the heterozygous class, which, from evidence obtained in the Rio × Baart cross, falls between the 25% and 75% levels of infection. In this cross we find a total of six progenies in the heterozygous class. The possible F_1 gametes and F_2 genotypes are shown in Table 3. In each cell is

TABLE 3.—*F_1 gametes and F_2 genotypes of cross between Turkey and Rio factors.*

Gametes	T R p	T r 1-p	t R 1-p	t r p
T R p	TT RR resistant p^2 (1)	TT Rr resistant p (1-p) (2)	Tt RR resistant p (1-p) (3)	Tt Rr segregating p^2 (4)
T r 1-p	TT Rr resistant p (1-p) (5)	TT rr resistant $1-2p+p^2$ (6)	Tt Rr segregating $1-2p+p^2$ (7)	Tt rr segregating p (1-p) (8)
t R 1-p	Tt RR resistant p (1-p) (9)	Tt Rr segregating $1-2p+p^2$ (10)	tt RR resistant $1-2p+p^2$ (11)	tt Rr segregating p (1-p) (12)
t r p	Tt Rr segregating p^2 (13)	Tt rr segregating p (1-p) (14)	tt Rr segregating p (1-p) (15)	tt rr susceptible p^2 (16)

shown the genotype, behavior of F_3 progeny, and the proportion of individuals expected in this class in terms of p, where p equals the cross-over percentage. According to this scheme, there will be eight segregating classes. Of these, however, those represented by cells 7 and 10 will only produce susceptible plants in the F_3 as the product of two cross-over gametes in the F_2, which with close linkage would give considerably less than 25% susceptible plants. Therefore, these classes may be considered in the resistant group. From the remaining six classes we can calculate a linkage value by setting the sum of the expected values equal to the observed number and solving for p. This gives $\frac{n}{4}\,[2p^2 + 4(p - p^2)] = 6$, or $p = 2.4\%$ crossing over.

Obviously this is a very rough estimate of linkage, since the separation of heterozygous and resistant classes is not exact and the estimate is based on such a small number of heterozygous individuals.

However, if this figure approaches the correct value, we would expect to find only about one susceptible row out of every 2,000. This accounts for the absence of susceptible progenies in this F_3 population of 248. Further evidence indicating that this estimate approaches the correct magnitude is found in the analysis of the next cross.

RIO × MARTIN

Table 1 shows that susceptible progeny occur in the cross Rio × Martin, indicating that the factor in Rio differs from the Martin factor. On the basis of two independent factors involved in this cross, one from each parent, we would expect 16 susceptible progenies in the population of 254. Actually only five fall above the 75% level of infection. This indicates the possibility of further linkage. This is to be expected, since Briggs (11) has shown that the Martin factor is linked with the Turkey factor with 34.22% crossing over, and it has just been demonstrated that the Rio and Turkey factors are linked.

An estimation of linkage based on the susceptible class can be computed from the formula $p = \sqrt{\frac{4b}{n}}$, where p = cross-over percentage, b = the susceptible class, and n = total population. The standard deviation of p is equal to $\sqrt{\frac{4-p^2}{4n}}$ according to Hutchinson (13). Substituting in these equations and solving, we obtain: $p = 28.1 \pm 6.16\%$. This is in accordance with the figure of 34.22% given for the linkage between the Martin and Turkey factors and the estimate of 2.4% linkage between the Rio and Turkey factors. From this evidence it appears that the Rio factor lies between Turkey and Martin factors and rather close to the Turkey factor. The error of estimating the linkage, however, is too great to establish definitely the order of the genes on the chromosome without further study.

DISCUSSION

Reference was previously made to the discovery of a factor for bunt resistance in Turkey 10016, designated as the XX factor by El Khishen (unpublished). This factor allowed 25% infection when in a homozygous condition and 60% infection when heterozygous. For Rio the figures are 10% infection when homozygous in the presence of modifiers and 50% when heterozygous. The fact that the XX factor behaved independently in crosses involving the Turkey and Martin factors precludes the possibility of its being identical with the Rio factor. Evidence has been given to show that the factor in Rio differs from the Martin, Hussar and Turkey factors. Therefore, the factor dealt with in Rio must be a new factor and shall be designated as the Rio factor and assigned the symbol RR.

El Khishen also found evidence that a weak factor YY occurring in Turkey 10015 was linked with the Turkey and Martin factors. What the relationship between this factor and the Rio factor is still remains to be investigated. Crosses have been made between Rio and Turkey 10015 and Turkey 10016 for further studies along this line.

At least three, and possibly four factors for bunt resistance lie on the same chromosome. To make an accurate determination of the linkage values between these factors it will be necessary to find some morphological character which belongs in the same linkage group. The basing of the estimate of linkage on the double recessive class of a bifactorial ratio in which the limits of the double recessive class are not accurately fixed induces too much error of estimation. However, the evidence that linkage does exist is conclusive.

SUMMARY

Evidence is presented which demonstrates the existence of a new factor for bunt resistance in Rio wheat. This factor is designated as the Rio factor and assigned the symbol RR. When present in the heterozygous condition this factor permits about 50% of the plants to become infected.

Factors present in Baart wheat modify the effect of the Rio factor, allowing a small percentage of the plants to become infected.

The Rio factor is found to be closely linked with the Turkey factor and more loosely linked with the Martin factor.

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THE EFFECT OF RATE OF PLANTING ON YIELDS OF ADAPTED AND UNADAPTED RED CLOVER[1]

E. A. Hollowell and David Heusinkveld[2]

IN conducting experiments comparing varieties, strains, or seed sources of red clover differing in adaptation to the environment, the establishment of uniform initial complete stands and the harvesting of weed-free forage are necessary prerequisites in order to obtain reliable comparisons. In general the acquiring of such uniform stands is facilitated by relatively high seeding rates which in turn reduces the prevalence of weeds.

Variation in adaptation among individual plants has occurred within every strain or seed source of red clover that has been studied. This is to be expected since red clover is in a hybrid state because of self sterility. In addition the heterozygosity in red clover is perpetuated by promiscuous insect cross pollination. The question arose as to whether heavy seeding rates might increase the surviving proportion of more nearly adapted plants from a relatively unadapted source to the extent of leveling off differences in plot yields between adapted and unadapted strains.

Consequently, this experiment was undertaken to determine whether seedings slightly higher than normally recommended would provide comparable initial stands, eliminate the error associated with the prevalence of weeds, and maintain the same relative differences in yields of adapted and unadapted red clover seed.

MATERIAL AND METHODS

The experiment was conducted during the period of 1929–33 at the Northwestern Experiment Farm of the Ohio Agricultural Experiment Station, Holgate, Ohio. Red clover seed of Ohio, western Oregon, and French origin was selected to provide plants with varying differentials of factors of adaptation. The former two seed sources represented seed that had been grown in the respective states for many plant generations, while the French seed was obtained from a reliable French source. The soil at this station is a Brookston clay, level in topography, of good productivity and exceptionally uniform.

Since the physical condition of the seedbed greatly influences stand establishment, the preparation of the seedbed consisted of plowing, disking, harrowing, floating, and thorough rolling. A companion crop of oats was seeded at the rate of 1 bushel per acre crosswise of the plots previous to the clover seeding. The seed was planted in systematic triplicate plots in 1929, 1930, and 1931 and in systematic quadruplicate plots in 1932 at the rates of 5, 10, 15, and 20 pounds per acre with seeding rates based on 100% germinable seed. Plot size in 1929, 1931, and 1932 was 7 feet × 96.8 feet and in 1930, 7 feet × 80 feet. Seedings were made

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Agronomy Department, Ohio Agricultural Experiment Station. The experiments were conducted at the Northwestern Experiment Farm of the Ohio Agricultural Experiment Station, Holgate, Ohio. Received for publication February 5, 1941.

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with a calibrated clover and alfalfa seed drill which distributed the seed in rows 4 inches apart.

The yield data were obtained the year following the seedings on two crops in 1930, 1931, and 1932. Only the first crop was harvested in 1933 since a severe drought prevented the development of sufficient second growth for harvesting. The weeds were removed from all plots before harvesting, except in the second cutting of 1931 when weed estimates were made and deducted from the green weights of each plot.

Border effect was eliminated by removing the ends of all plots before harvesting and by cutting a mower swath 4.7 feet wide through the center of each plot for yields. Green weights and one shrinkage sample of approximately 5 pounds were taken from each plot immediately after cutting. Shrinkage samples were artificially dried to prevent spoilage and later were reduced to a moisture-free basis. Yields of plots were calculated in tons per acre on a dry-matter basis, using the shrinkage sample data.

RESULTS AND DISCUSSION

The results of these studies are presented in Table 1. It is obvious from an inspection of the data that the 5-pound rate of seeding did not provide sufficient plants for maximum yields. It is also apparent that the differences between the 10-, 15-, and 20-pound rates were of no consequence. There was a marked reduction in the percentage of weeds in the plots from the 5-pound to the 10-pound rate. In general, the plots seeded at the 15- and 20-pound rates contained

TABLE 1.—*Effect of rate of planting on weed-free hay yields of Ohio, Oregon, and French red clover, Holgate, Ohio, 1930–33.*

Seed source	Tons of moisture-free hay per acre				
	1930*	1931*	1932*	3-year average	First crop, 1933
		5-lb. Rate of Seeding			
Ohio	1.12	1.92	2.00	1.68	0.84
French	0.60	1.25	1.49	1.11	0.48
Oregon	0.64	1.29	1.32	1.08	0.53
		10-lb. Rate of Seeding			
Ohio	1.23	2.10	2.01	1.78	0.97
French	0.75	1.61	1.55	1.30	0.49
Oregon	0.73	1.33	1.40	1.15	0.60
		15-lb. Rate of Seeding			
Ohio	1.18	2.05	1.96	1.73	0.97
French	0.81	1.68	1.55	1.35	0.49
Oregon	0.78	1.33	1.46	1.19	0.57
		20-lb. Rate of Seeding			
Ohio	1.21	1.96	1.92	1.70	0.95
French	0.65	1.71	1.53	1.29	0.46
Oregon	0.83	1.43	1.47	1.25	0.60

*Two crops each season.

fewer weeds than the 10-pound seeding. More uniform initial stands occurred at the 15- and 20-pound rates than at the 5- and 10-pound rates, and this was particularly true during the seasons that were unfavorable for seedling establishment.

The data were subjected to an analysis of variance. It is believed that the unusual uniformity of the soil, as was evidenced by the similarity of yields of replicated plots and observations on plant development, would materially reduce any bias brought about by a lack of randomization. The very low mean square for error found in the analysis indicates that the test area was relatively uniform. As was evident from calculated yields and plant observations, the differences between varieties, rates, and years proved to be highly significant. The interactions between varieties X years and blocks within years were also highly significant; however, the mean square for blocks within years was much less than any other of the previously mentioned mean squares. The first order interactions, varieties $\times$ rates, rates $\times$ years, and the second order interaction, varieties $\times$ rates $\times$ years, were not significant. Since the effect of rates is of primary interest, a further partition of the contribution for rates showed highly significant differences between the 5-pound rate and each of the others. No significant differences were found between the 10-, 15-, and 20-pound rates.

As is evidenced by the hay yields, the growing seasons of 1930 and 1933 were unusually dry, while those of 1931 and 1932 were favorable for plant growth. A partitioning of the year data into dry years versus moist years did not significantly change the interpretation of the results.

An increase of the seeding rate in red clover strain experiments to 15 pounds per acre may be made since the acquiring of comparable initial stands and the reduction of weeds in plots are facilitated by such a practice without changing the differences of the comparisons. Recommendations on the rate of seeding of red clover under farm conditions should not be made from the data since seedbed preparation was more thorough in these studies than can be expected on the farm.

SUMMARY

Red clover seed of Ohio (adapted), western Oregon (unadapted), and French (unadapted) origins was seeded at the rates of 5, 10, 15, and 20 pounds per acre in systematic replicated plots for the yield determinations in 1930 to 1933, inclusive, at Holgate, Ohio.

Increasing the seeding rates from 10 to 20 pounds per acre did not significantly change the relative yields of adapted and unadapted red clover.

An increase in the seeding rate from 10 to 15 and 20 pounds per acre provided more uniform initial stands.

THE EFFECT OF ADDING VITAMIN B_1 (THIAMIN) TO SEVERAL GRASS SPECIES[1]

GILBERT H. AHLGREN[2]

DURING the past year various investigators have repeatedly pointed out the significant relationship between the production of vitamin B_1 in the green leaves of growing plants and its translocation to the roots of these plants where it produces a marked stimulating effect on root elongation. Experimental evidence has been presented to show that some plant species are capable of synthesizing in the presence of light sufficient vitamin B_1 in their leaves for maximum growth (3, 4).[3] In other plant species, however, the amount of vitamin B_1 produced in the leaves is relatively small and might conceivably act as a limiting factor in plant growth and development. This is thought by some workers to be true in the "slow-growing" plants, particularly horticultural species, although there is little evidence available confirming this assumption.

The hormone action of vitamin B_1 in stimulating root elongation has been experimentally demonstrated on excised pea (1) and tomato roots (7). During seed formation large quantities of this vitamin are stored in the aleurone layer, as in barley or wheat, and in the cotyledons, as in the pea (5). The presence of vitamin B_1 is readily demonstrated in such forms of organic matter as manure, peat, composts, and decomposing plant constituents and therefore is probably present in soils which contain any of these materials.

Recently, Bonner and Greene (4) presented evidence showing a stimulating effect on top growth of vitamin B_1 additions in nutrient solution to rough-stalked meadow bluegrass (*Poa trivialis*) and Colonial bent grass (*Agrostis tenuis*) growing in sand cultures. Whereas it was the original purpose of the study herein reported to determine the effect of additions of vitamin B_1 in nutrient substrate to cultures of Kentucky bluegrass, the failure to secure any response whatever by this species prompted experimentation with *Poa trivialis* and *Agrostis tenuis*. Since the completion of the experimental work of this study, Arnon (2) and Hamner (6) have reported only negative responses by several plant species to additions of vitamin B_1 supplied in nutrient media. Among the species which they studied were cosmos, mustard, and cocklebur, previously reported by Bonner and Greene (4) to give a stimulatory response.

EXPERIMENTAL PROCEDURE

A standard culture solution (5) with reduced concentration was added to seeds of commercial *Poa pratensis* germinated on filter paper in sterile petri dishes.

[1]Journal Series paper of the New Jersey Agricultural Experiment Station, New Brunswick, N. J., Department of Plant Physiology. Received for publication February 8, 1941.

[2]Research Assistant in Agronomy. Appreciation is extended to Dr. J. W. Shive and to Dr. W. Rei Robbins of the Plant Physiology Department and to Dr. H. B. Sprague of the Agronomy Department for helpful criticisms and encouragement during the course of this experiment.

[3]Figures in parenthesis refer to "Literature Cited", p. 576.

When the seedlings were about 2.5 cms high they were transplanted to screened acid- and alkali-washed sand in 3-gallon glazed crocks with good drainage, 12 uniform seedlings being placed in each of 12 cultures. These cultures were in turn divided into two groups so that the calcium nitrate supplied in nutrient solution to six cultures had a partial volume molecular concentration of 0.0045 and the calcium nitrate supplied in nutrient solution to the other six cultures had a partial volume molecular concentration of 0.00018. These two groups were randomized and sub-divided so that three cultures in each group received vitamin B_1 at the rate of 0.01 mg per liter of solution and the other three served as controls. Thus, a total of 36 Kentucky bluegrass plants were under trial for each of four treatments. The medium and low concentrations of nitrate nitrogen were used with Kentucky bluegrass in order to determine whether the synthesis of vitamin B_1 might be related to nitrogen metabolism and vegetative vigor as indicated by growth rates.

Homogenic cuttings which undoubtedly contained minute traces of vitamin were taken from one plant each of *Poa trivialis* and *Agrostis tenuis* and first placed in acid- and alkali-washed sand. A standard nutrient solution of reduced atmospheric concentration was supplied to these cuttings and within one week the cuttings had become well rooted and were transplanted to the experimental crocks. Six crocks each containing eight uniform cuttings were alloted to each species. Finally, three cultures (24 cuttings) from each species were supplied with vitamin B_1 at the rate of 0.01 mg per liter of culture solution and the remaining cultures served as the controls. In this experiment all of the cultures were supplied with a solution containing calcium nitrate at a partial volume molecular concentration of 0.0045. The cultures were randomized in two rows along a single supporting bench in the greenhouse.

The culture medium used as a basis of operation was Shive's (9) three-salt solution modified to meet the requirements of the experiment. The modifications are given in Table 1.

TABLE 1.—*Composition of nutrient solutions.*

Solution type	Partial vol. mol. conc. of nutrient salts*			
	KH_2PO_4	$Ca(NO_3)_2$	$MgSO_4$	$CaCl_2$
1	0.0023	0.00018	0.0023	0.00432
2	0.0023	0.0045	0.0023	———

*Boron, iron, manganese, and zinc were added at the rate of 0.25, 0.1, 0.1, and 0.1 p.p.m., respectively.

The amount of calcium chloride added to the solution was enough to replace any calcium nitrate that was taken away. Such a replacement permits varying the nitrogen content while maintaining the calcium at a uniform concentration. Approximately 1 liter of solution was supplied daily by the continuous flow method of Shive and Stahl (8). One liter of fresh solution was flushed through each of the cultures daily, thus obviating the accumulation of salts through the loss of water by evaporation and transpiration. A fresh stock solution of vitamin B_1 was made up at weekly intervals and kept in a refrigerator at low temperature to insure its preservation.[4]

[4]Synthetic vitamin B_1 hydrochloride in the crystallized form obtained from Merck and Company, Rahway, N. J.

Germination of seed of Kentucky bluegrass was begun on February 8 and the young seedlings were transplanted to the experimental crocks on February 15. The first harvest of top growth was taken on May 6. It was intended to make a second clipping, but this growth was injured in spraying for aphids and had to be discarded. The roots were harvested immediately after injury to the tops on May 23. Vegetative cuttings of rough-stalked meadow bluegrass and Colonial bent grass were made on June 16 and were transplanted to the experimental cultures on June 24. The first top cutting was made on August 8 and the second clipping and the roots were harvested on September 28.

EXPERIMENTAL RESULTS

During the entire course of these experiments it was impossible to note any real differences between comparative replications. These observations are borne out by the data presented in Table 2.

TABLE 2.—*Dry matter yield in grams of top and root growth of three grass species grown in nutrient solutions with and without additions of vitamin B_1.**

	Nutrient without vitamin B_1		Nutrient with vitamin B_1	
	Top growth	Roots	Top growth	Roots
	Kentucky Bluegrass			
Med. N series	18.34	7.9	17.58	7.6
Low N series	3.43	0.6	3.33	0.6
	Colonial Bent Grass			
1st clipping	8.49	—	8.77	—
2nd clipping	4.78	4.24	4.59	4.28
	Rough-Stalked Meadow Bluegrass			
1st clipping	9.78	—	9.28	—
2nd clipping	6.42	5.18	6.35	5.20

*Each figure is average of three replicates.

The dry weights presented in Table 2 show that Kentucky bluegrass did not respond to additions of vitamin B_1 in nutrient solutions of medium and low nitrate concentrations when the vitamin was supplied at the rate of 0.01 mg per liter of solution. Similar results can be noted for Colonial bent grass and for rough-stalked meadow bluegrass. Representative cultures of these two species are shown in Fig. 1.

The results of these experiments have been corroborated under conditions of varying soil fertility.[5] In all cases negative responses resulted from additions of vitamin B_1.

SUMMARY

Cultures of *Poa pratensis*, *P. trivialis*, and *Agrostis tenuis* were grown under greenhouse conditions in sand cultures to study the

[5]Unpublished data.

effect of additions of vitamin B_1. The continuous flow method was used to apply the nutrient solution.

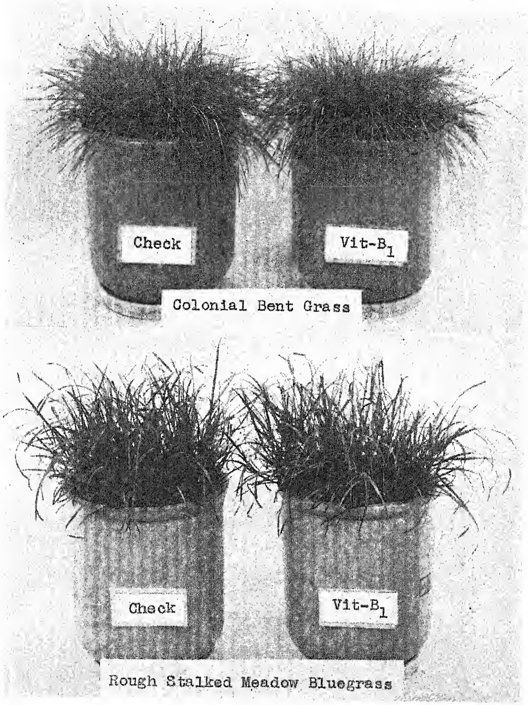

FIG. 1.—No evidence of growth stimulation was found in these cultures. The control plants grew just as well as did the plants supplied vitamin B_1 in nutrient solution.

Additions of 0.01 mg per liter of vitamin B_1 had no effect on the dry matter accumulation of tops and roots of *Poa pratensis* under conditions of either a medium or a low nitrate concentration in nutrient media. The plants were grown from seed.

Additions of 0.01 mg per liter of vitamin B_1 had no effect on the dry matter accumulation of tops and roots of *Poa trivialis* and *Agrostis tenuis* when a nutrient solution containing a medium nitrate concentration was added. These two species were grown from cuttings.

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IRREGULAR GERMINATION OF WHEAT IN A DRY SOIL[1]

V. C. Hubbard[2]

WINTER wheat frequently is sown in dry soil in the Southern Great Plains, and, under such conditions, germination is delayed until rains come. During the season of 1939–40 at the Southern Great Plains Field Station, Woodward, Okla., the germination and emergence of wheat continued over a period of about 5.7 months. Because such a season is very unusual the conditions attendant thereto will be of interest.

The fall of 1939 was the driest since the inception of weather records in Woodward County, Okla., in 1873. The last effective rain, totaling 1.16 inches, occurred on July 22. By September 15, when seeding began, 3 to 6 inches of the surface soil was very dry, although below these depths there was ample moisture to a depth of 7 feet. No effective rain was received during the seeding period. In September and October there were but three showers, the largest 0.08 inch. A rain of 0.34 inch on November 9 prompted the germination of only a relatively small number of seeds and left a light crust which retarded the emergence of seedlings.

In the previous 9 years the average date of emergence was September 21, October 7, October 22, November 14, and December 9 for wheat seeded approximately September 15, October 1, October 15, November 1, and November 15, respectively. During those years the maximum period observed from seeding to emergence was 34 days as compared with 100 to 170 days in 1939.

In an attempt to reach moist soil in 1939 the wheat was sown as deep as a single disk drill would penetrate, roughly 2 to 3 inches. A hard layer of soil prevented deeper seeding. The seed reached varying amounts of moisture. On September 21 an estimated 5% of plants were emerging and continuous but slow, irregular emergence occurred from then until early in March. After December 13, wheat sown on all five dates from September 15 to November 15 showed irregular root and top development similar to that illustrated in Fig. 1.

Cool weather after October 1 prevented appreciable top growth of any plants emerging after that date.

Sprouts that were 1 inch long or longer and still under ground, were for the most part yellowish-green to yellow in color and fresh in appearance, although a few 2½ inches long were entirely green. About 10% of the sprouts were 2 to 2½ inches long on December 13 and approximately half of these were slightly to severely bent or crinkled. The crinkled leaves had grown to various lengths but failed to emerge, and a few of the seedlings lived in this crinkled condition for more than 90 days before dying. Few leaves were observed to crinkle after the snow of December 22. The snow covering, varying from a trace to 6 inches, was gone by January 29. Many plants emerged

[1]Contribution from the Division of Cereal Crops and Diseases and the Division of Dry Land Agriculture, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication March 3, 1941.

[2]Junior Agronomist.

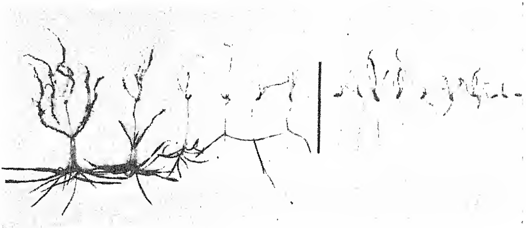

FIG. 1.—Range of development of roots and tops of winter wheat on December 13 from a September 15, 1939, seeding at Woodward, Okla. Emerged (right) and not emerged (left). Photograph by L. F. Locke.

under the snow and stands were nearly 50% better when the snow left than before it fell.

A minimum temperature of -6° F on January 7 and 8 caused little or no damage to non-emerged seedlings even though the ground was frozen from a trace to 18 inches deep, depending upon the depth of snow cover. Various degrees of injury were noted in the above-ground plant parts, but no plants were killed by this low temperature.

Stands were thin, being 75 to 80% of normal. Plants developed slowly in the spring but, because of the thin stands, they tillered more than usual producing an average of 9.6 tillers and 9.0 heads per plant; whereas a normal stand of plants in a normal season develops 3.5 tillers and 3.1 heads per plant on the average.

It is evident from the data presented in Table 1 that the dates of heading and maturity were delayed though not nearly to the extent of the delay in emergence. Harvesting was a problem because the

TABLE 1.—*Average dates of seeding, emergence, heading, maturity, and yield of the 1939–40 winter wheat crop as contrasted with normal development at the Southern Great Plains Field Station, Woodward, Okla.*

Seeding dates in 1939 and in each of previous 9 years*	Emerged		Headed		Ripe		Average yield in bushels per acre	
	1940 crop	9-year av.	1940 crop	9-year av.	1940 crop	9-year av.	1940 crop	9-year av.
Sept. 15	Sept.†	Sept. 21	May 10	May 10	June 25	June 12	18.7	21.2
Oct. 1	Oct.	Oct. 7	May 18	May 10	June 25	June 12	16.7	23.3
Oct. 15	Nov.	Oct. 22	May 23	May 10	June 26	June 13	16.2	23.2
Nov. 1	Dec.	Nov. 14	May 23	May 15	June 26	June 16	18.3	20.9
Nov. 15	Jan.	Dec. 9	May 25	May 20	June 27	June 20	16.9	19.5

*The seeding dates may have varied one or two days from those given due to rain, holidays, etc.
†September 15 seedings in 1939 emerged continuously from September 21 to early March. Similarly, later dates of seeding emerged continuously into March.

plants from all five dates of seeding ripened very irregularly. Ripe, shattering, and green heads were evident in each plot and frequently shattered, ripe, and green kernels were noted in a single head.

Grain yields varied little in 1940 since the bulk of all the seedings emerged at approximately the same time in late December and early January. Slightly more favorable moisture conditions in September and early November accounted for a few more plants emerging and for the slightly higher yields from the September 15 and November 1 seedings.

CONCLUSIONS

The surprisingly favorable yield data obtained from seedings made under the extremely adverse conditions in 1939–40 might be construed to indicate the advisability of sowing routine plot and nursery experimental seedings for yield tests within pre-agreed upon dates, regardless of the chance of immediate emergence. Such sowings would give a yield or a failure, whereas if no seedings were made the question would always arise as to what might have happened had a sowing been made.

Unnecessary risks with limited seed of hybrid nursery material is, of course, not suggested.

BOOK REVIEW

HUNGER SIGNS IN CROPS

Edited by Gove Hambidge. Washington, D. C.: Judd & Detweiler, Publishers. XIII + 327 pages; 174 figs., 79 in color. 1941. $2.50.

THIS practical text on mineral nutrition of agricultural crops, compiled by eminent American agronomists, chemists, and soils experts, represents a new departure in documentation of the subject. It is profusely illustrated with 79 excellent natural color plates of the diagnostic symptoms of nutrient deficiencies and 95 figures in black and white of growth habits of normal and malnourished crops. The color plates alone make the book indispensable to agriculturists and plant scientists, especially in view of the modest cost. These well-selected illustrations permit ready visualization of the important deficiency symptoms discussed in the extremely lucid, yet concise text.

The book comprises nine chapters as follows: 1, Why do Plants Starve?, by G. D. Scarseth and R. M. Salter; 2, Plant-Nutrient Deficiency in Tobacco, by J. E. McMurtrey, Jr.; 3, Deficiency Symptoms of Corn and Small Grains, by George N. Hoffer; 4, Plant-Nutrient Deficiency Symptoms in the Potato, by H. A. Jones, and B. E. Brown; 5, Plant-Nutrient Deficiency Symptoms in Cotton, by H. P. Cooper; 6, Plant-Nutrient Deficiencies in Vegetable or Truck-Crop Plants, by J. J. Skinner; 7, Nutrient-Deficiency Symptoms in Deciduous Fruits, by O. W. Davidson; 8, Plant-Nutrient Deficiency Symptoms in Legumes, by E. E. DeTurk; and 9, Symptoms of Citrus Malnutrition, by A. F. Camp, H. D. Chapman,

George M. Bahrt, and E. R. Parker. A complete table of contents and index permit rapid reference.

The symptoms of deficiency are discussed in each chapter under a separate heading for each nutrient element, an arrangement which facilitates rapid scrutiny. As a diagnostic aid in determining causes of injury, there is included at the end of most of the chapters a systematic key to the external deficiency symptoms commonly occurring in the crops under discussion. A brief but carefully selected bibliography on mineral nutrition concludes each chapter.

The context concerns itself chiefly with the specific external, macroscopic symptoms of malnutrition as these apply to the general configuration of the plant as a whole, as well as to foliage, stems, roots, and reproductive structures. Edaphic growth factors, such as pH, soil texture, nutrient interaction, and secondary susceptibility to infectious disease, are discussed as these relate to ordinary mineral deficiencies. Remedial measures, selection and dosage of appropriate fertilizers, fertilizer requirements and placement, as well as helpful cultural practiees, are succinctly described. Specific methods for direct chemical tests on tissues are included wherever appropriate. Some attention is given to internal evidences of malnutrition which have diagnostic value, but reference to technical aspects of microscopic anatomy has been excluded. Included, however, are descriptions of variation in symptoms of under-nourishment due to age of the plant, season, climate, and ordinary cultural practices. Carefully considered avoidance of technical terminology adapts the text to use of agriculturists without sacrifice of scientific accuracy or precision.

The widespread need for a book of this type is reflected by the fact that prepublication subscriptions alone insured the financial success of this expensive undertaking. The book also stands as a monument to the professional devotion of the scientists who prepared it without thought of monetary profit. This publication indicates the possibilities of constructive collaboration between scientific and commercial organizations. The American Society of Agronomy deserves commendation for initiation of the project as does the National Fertilizer Association for its subsidy of publication costs. This book combines an unusually high quality of format and usefulness of context with economy of cost. It will render an important service to American agriculture for many years to come. In the words of the book's editor, "So wide a range of material on malnutrition symptoms in plants has not before been brought together in a single volume."—WALTER F. LOEHWING, *Department of Botany, State University of Iowa, Iowa City, Iowa.*

AGRONOMIC AFFAIRS

THE 1940 PROCEEDINGS OF THE SOIL SCIENCE SOCIETY

THE PROCEEDINGS of the 1940 meeting of the Soil Science Society of America is now available for distribution. The volume is almost identical in size with Volume 4 for 1939, with 448 pages, In addition to the papers presented at the annual meeting in Chicago, December 4 to 6, 1940, the volume contains committee reports, the minutes of

the business meeting, committee appointments for 1941, a summary of program regulations, and other miscellaneous announcements.

Copies of Volume 5 may be obtained from Dr. G. G. Pohlman, Treasurer, West Virginia Agricultural Experiment Station, Morgantown, W. Va., for $5.00 post paid.

ABSTRACTS OF PROGRAM PAPERS

BY action of the Executive Committee of the Soil Science Society, abstracts of papers to be presented at the meeting in Washington, D. C., in November will be mimeographed by the Section Chairmen and made available to interested persons in advance of the meeting through the office of the Treasurer of the Society, Dr. G. G. Pohlman, West Virginia Agricultural Experiment Station, Morgantown, W. Va. A charge of 10 cents will be made to cover the cost of mailing.

All persons who plan to submit papers on the various Section programs are urged to supply abstracts to the Section Chairmen as soon as possible.

FOREIGN SUBSCRIPTIONS AND MEMBERSHIPS

BECAUSE of the uncertainty of communication systems, the American Society of Agronomy does not feel that it can any longer be responsible for the delivery of the JOURNAL to European, Asiatic, or North African countries now at war or within the war zones.

It is suggested that members and subscribers in these regions may have copies of the JOURNAL held for them until after the war; or if they wish to assume the responsibility for delivery, any failure to receive copies of the JOURNAL shall not be deemed the responsibility of the American Society of Agronomy. Members and subscribers in these areas shall be expected to pay the regular rates for replacement of copies lost in transit if they wish delivery continued.

These provisions will go into effect July 1, 1941.

AGRONOMIC INSTRUCTION FOR MODERN AGRICULTURE

WORD comes from Dr. Ide P. Trotter, Head of the Department of Agronomy, Texas Agricultural and Mechanical College, of the second short course in "Soil Classification and Mapping" to be held at College Station, Texas, from July 21 to August 9.

The course will be conducted by E. A. Norton, Chief of Physical Surveys, Division of Soil Conservation, U. S. Dept. of Agriculture, and will be open to technical workers in soils, agronomy, or others having the B.S. degree in agriculture. Those interested should write to Doctor Trotter for further details.

GEOLOGIC PROGRAMS

A PRELIMINARY outline of geological programs to be held at the University of Chicago September 25 and 26 in celebration of the fiftieth anniversary of the University includes a half-day session on "Frontier Researches on the Structure, Properties, and Occurrence of Clay Materials and Their Practical Application" under

the leadership of Dr. Ralph E. Grim, petrographer of the Illinois Geological Survey.

Papers will include "Modern Concepts of Clay Materials", by R. E. Grim; "The Relation of the Lattice Structures of Clay Minerals to Some Properties of Clays", by S. B. Hendricks; "Applications of Modern Clay Researches in Agriculture", W. P. Kelley; "Applications of Modern Clay Researches in Ceramics", by F. H. Norton; and "Applications of Modern Clay Researches in Construction Engineering", by H. F. Winterkorn.

For further details regarding this program as well as other geologic programs to be presented in connection with the celebration, address inquiries to Professor Edson S. Bastin, Chairman, Department of Geology, Rosenwald Hall, University of Chicago.

SOUTHERN PASTURE AND FORAGE CROP IMPROVEMENT CONFERENCE

A CONFERENCE of technical workers in pasture and forage crop problems will be held July 19 to 22 at North Carolina State College, Raleigh, N. C., to be followed by a one-day Regional Grassland Conference open to the public, with Director R. M. Salter in charge of the general program. Pasture and forage crop work at outlying stations will be visited on Saturday and Sunday, Monday and Tuesday will be given over to programs developed around the following general themes: Methods for Measuring the Productivity of Pastures, R. L. Lovvorn, Chairman; The Place of Supplementary Feeds in Pasture and Range Experiments, E. H. Hostetler, Chairman; General Discussion on Breeding Technic for Forage Crops, H. R. Albrecht, Chairman; Methods for Evaluating New Strains of Grasses and Legumes, Glenn W. Burton, Chairman; and Methods of Evaluating New Grasses and Legumes for Miscellaneous Uses, John Monteith, Chairman.

PROGRAM FOR SECTION IV, SOIL SCIENCE SOCIETY

PLANS are now being formulated for the coming meeting of the Soil Fertility Section of the Soil Science Society of America. Attention is called to the request for titles of proposed papers by August 1 and for abstracts of the papers consisting of 200 words to be submitted with the title or by August 15.

Several sessions are planned with a central theme, but other sessions are being held open for contributed papers. There will be three half-day sessions on soil fertility problems alone. At least one joint session is scheduled with the Crops Section on "Pasture Fertilization and Management". Other topics to be discussed are the needs, sources, and use of magnesium in fertility practices; potassium investigations; and a miscellaneous session. Anyone planning on presenting a paper in this Section should communicate with the Section Chairman, James A. Naftel, Alabama Polytechnic Institute, Auburn, Ala.